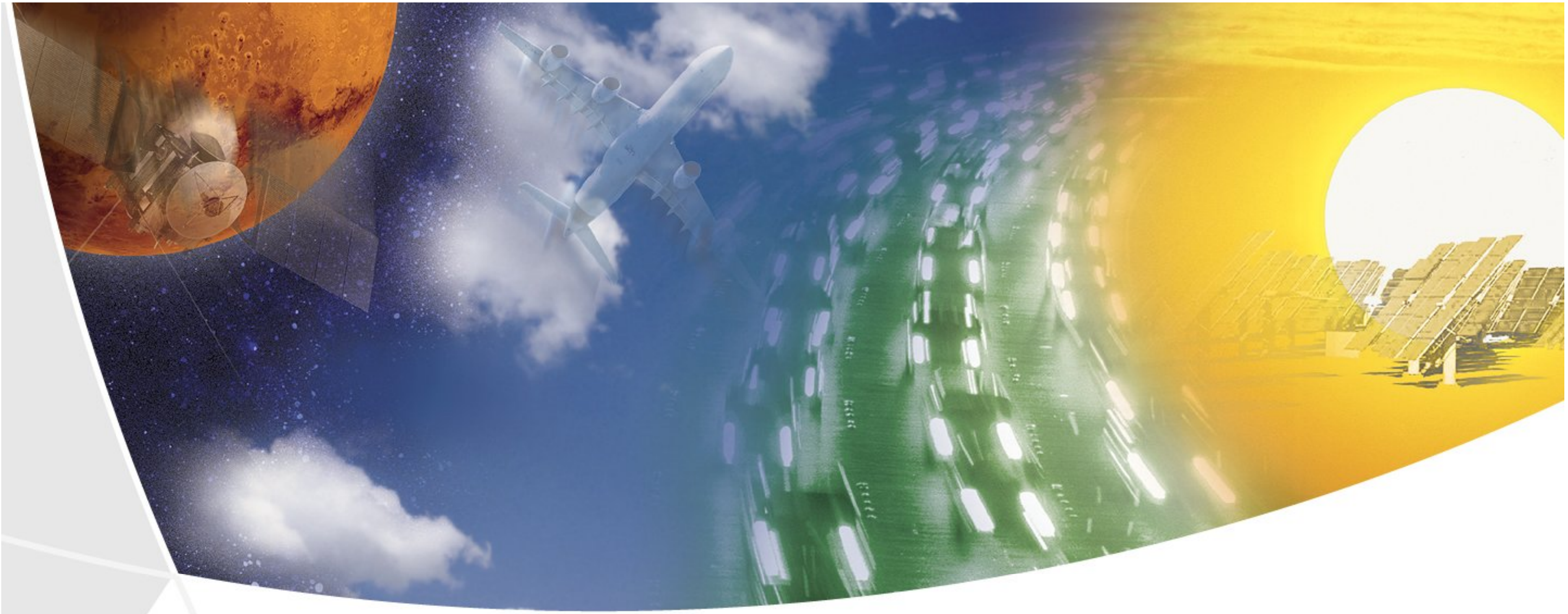

FROM THE ROSETTA LANDER *PHILAE* TO AN ASTEROID HOPPER: LANDER CONCEPTS FOR SMALL BODIES MISSIONS

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Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Outline

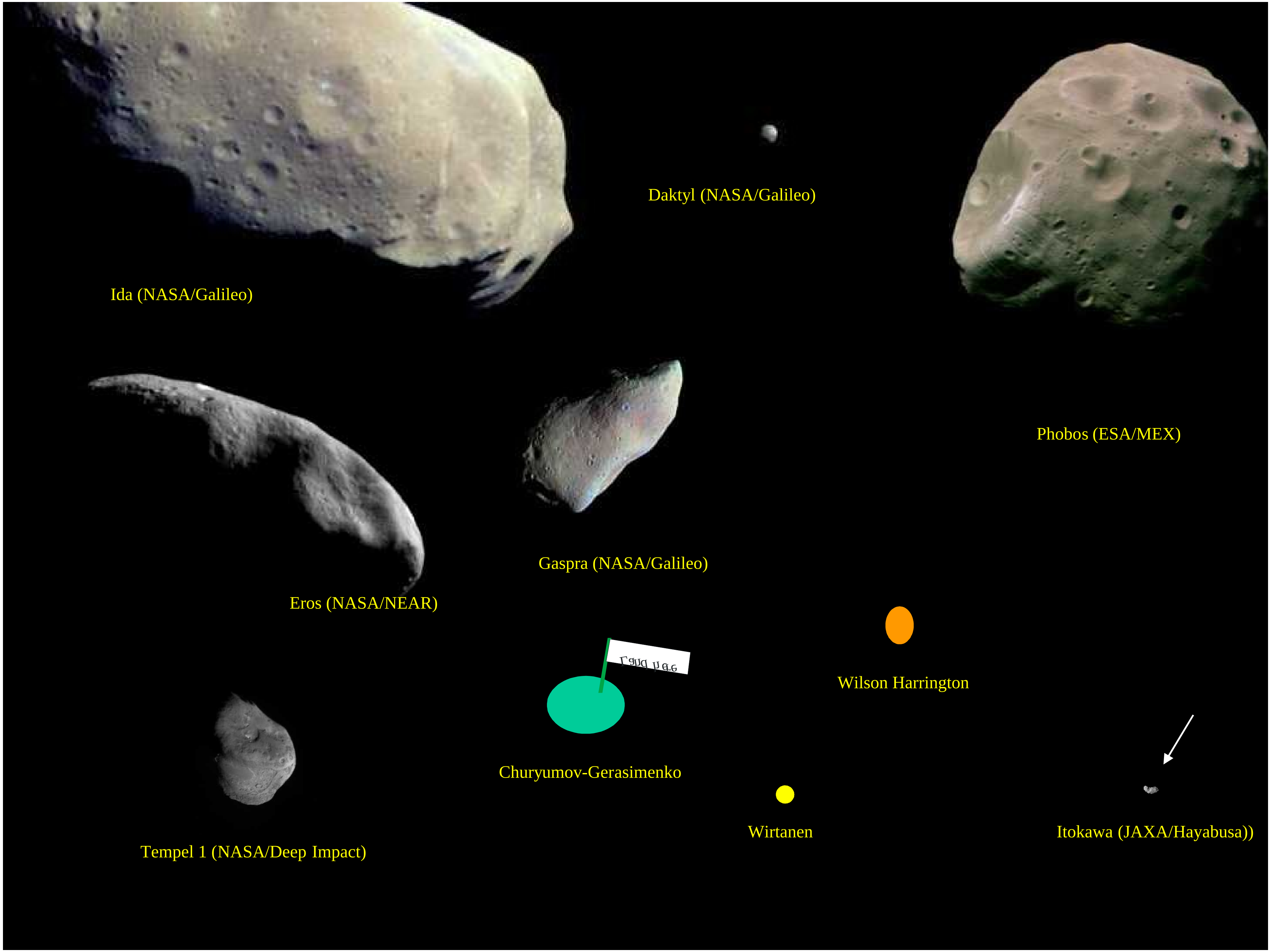
- The investigation of small bodies, comets and asteroids, can contribute substantially to our understanding of the formation and history of the Solar System.   In situ observations by Landers play an important role in this field.
- The Rosetta Lander – Philae – is currently on its way to comet 67P/Churyumov-Gerasimenko. Philae is an example of a ~100 kg landing platform, including a complex and highly integrated payload, consisting of 10 scientific instruments.
- Other lander designs, more lightweight and with much smaller payload are currently investigated in the frame of a number of missions to small bodies in the Solar System.
- We will address a number of possible concepts, including mobile surface packages.

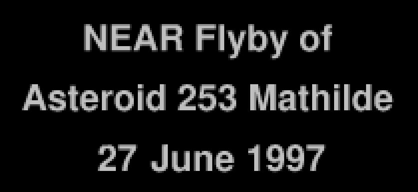
Background on small-body landers

- Historically, there are only two missions which reached the surface of a small body: the NEAR spacecraft touched down on asteroid Eros and Hayabusa attempted to take samples from the surface of Itokawa and recently returned to Earth.
- In-situ probes can deliver a much higher scientific return if mobility is possible to explore more than one site. We discuss mobility concepts for low-gravity environments including current developments (the MASCOT hopper).
- Missions aiming for sample return, e.g., asteroid sample return mission Hayabusa-2 , can be significantly enhanced by the implementation of in-situ surface packages → help to constrain the geological and physical context of the samples, provide a hold on the evolutionary history of the body by probing its interior.
- Mobility can even “scout” the most interesting sampling sites on the surface

Conditions when landing on Small Bodies

- Low gravity
  - Impact velocity can be chosen small even without thrusters (0.5-2 m/s)
  - Rebounce needs to be minimized
  - Anchoring to be considered
- Uncertainty regarding surface properties
  - Wide range of surface strength to be considered
  - Local slopes may be steep
  - Dust – ice – gas-jets
- Usually not spherical … "wobbling potatoes"
  - Rotation axis may be chaotic
  - Day night cycle at landing site not trivial to be estimated
  - Complex descent analysis necessary
- Large variations of temperature day/night, heliocentric distance


Ida (NASA/Galileo)
Daktyl (NASA/Galileo)
Phobos (ESA/MEX)
Eros (NASA/NEAR)
Gaspra (NASA/Galileo)
Wilson Harrington
Churyumov-Gerasimenko
Tempel 1 (NASA/Deep Impact)
Wirtanen
Itokawa (JAXA/Hayabusa))



Mathilde (NASA/NEAR)

Wild 2 (NASA/Stardust)

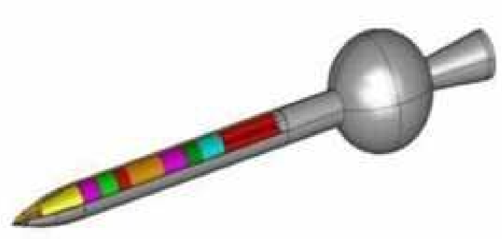
Phobos (ESA/MEX)

Tempel 1 (NASA/Deep Impact)

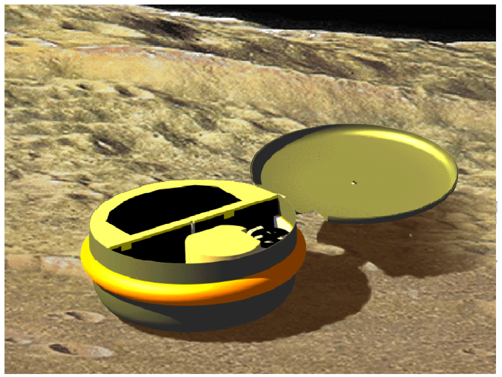
Halley (MPS/ESA/Giotto)

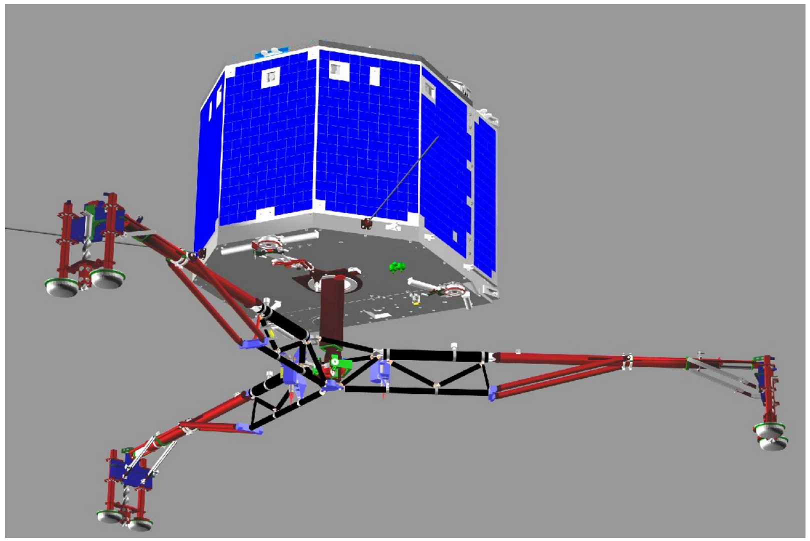
Itokawa (JAXA/Hayabusa))

Lander strategies



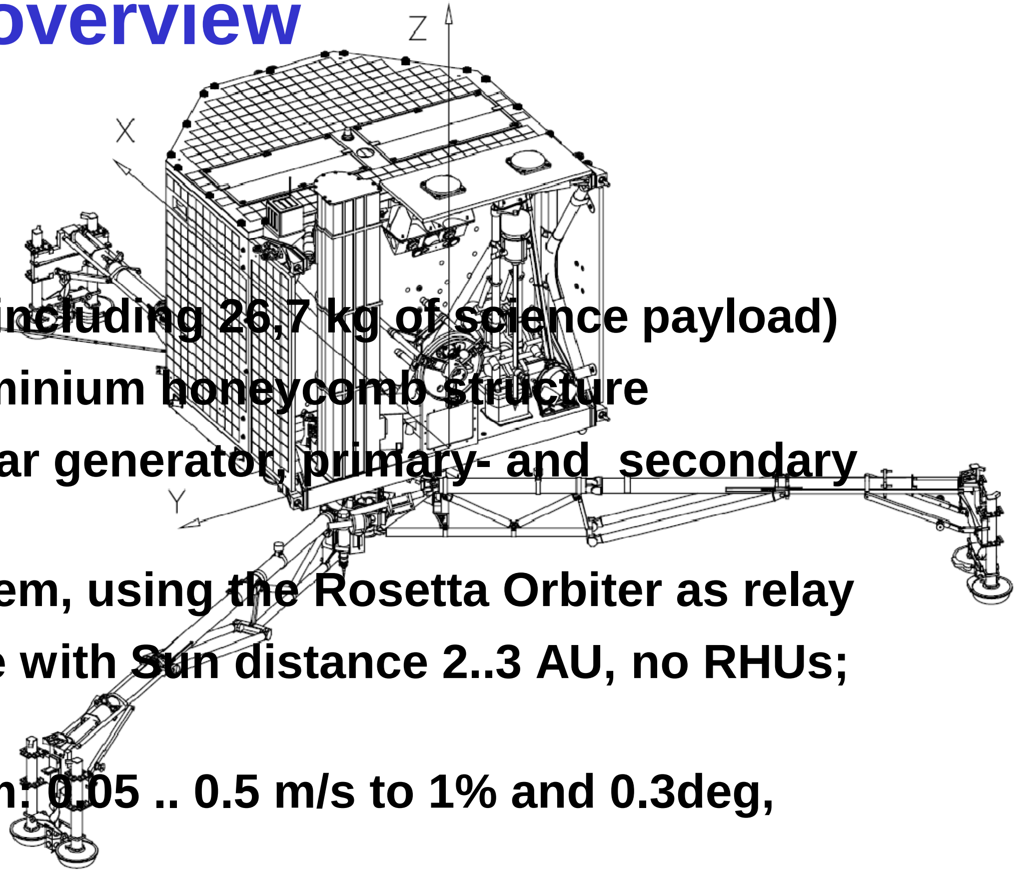
- Impactor / Penetrator: not considered!
- „Classical Lander“ with landing legs or platform (e.g. Philae, Phobos-Grunt)
- Hopper (e.g. Phobos Hopper)
- Opening shell (derivative from Mars Netlander)
- „Orbiter Landing“ (e.g. Hayabusa)





- Rosetta is an ESA cornerstone Mission to Comet 67P/Churyumov Gerasimenko
- 11 Orbiter Instruments plus the Lander
- Launch: March 2nd, 2004
- Arrival: May 2014,
- Lander separation: Nov.2014

Philae – system overview

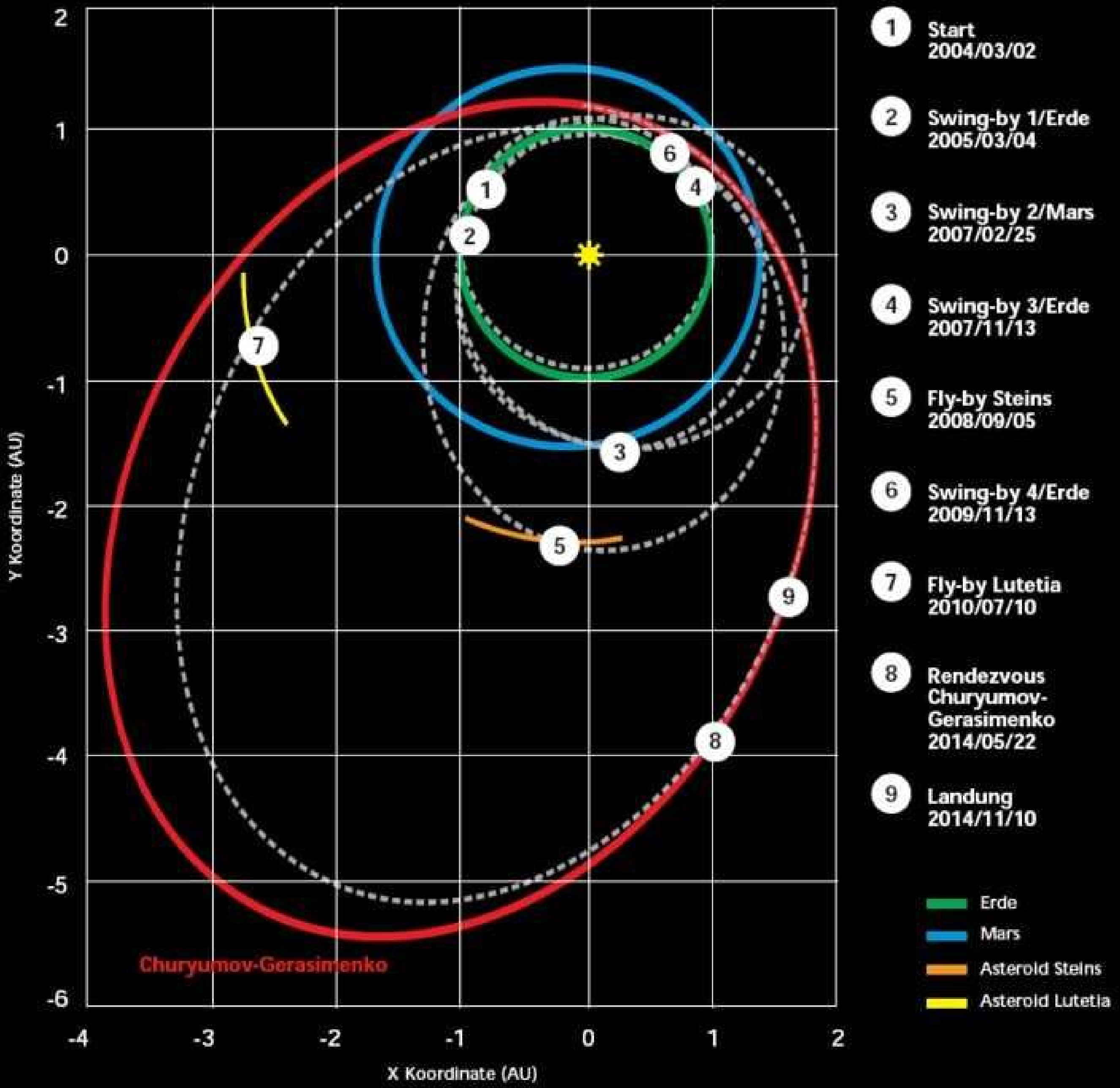


- Overall mass of about 98 kg (including 26,7 kg of science payload)
- based on a carbon fibre / aluminium honeycomb structure
- power system including a solar generator, primary- and secondary batteries
- S-band communications system, using the Rosetta Orbiter as relay
- Thermal control system: cope with Sun distance 2..3 AU, no RHUs; double MLI tent, absorbers
- Mechanical separation system: 0.05 .. 0.5 m/s to 1% and 0.3deg, emergency spring eject
- Landing Gear: tripod - dissipate landing energy, provide TD signal,
- Change of target comet (Wirtanen to Churyumov-Gerasimenko) prompted stiffening of LG.

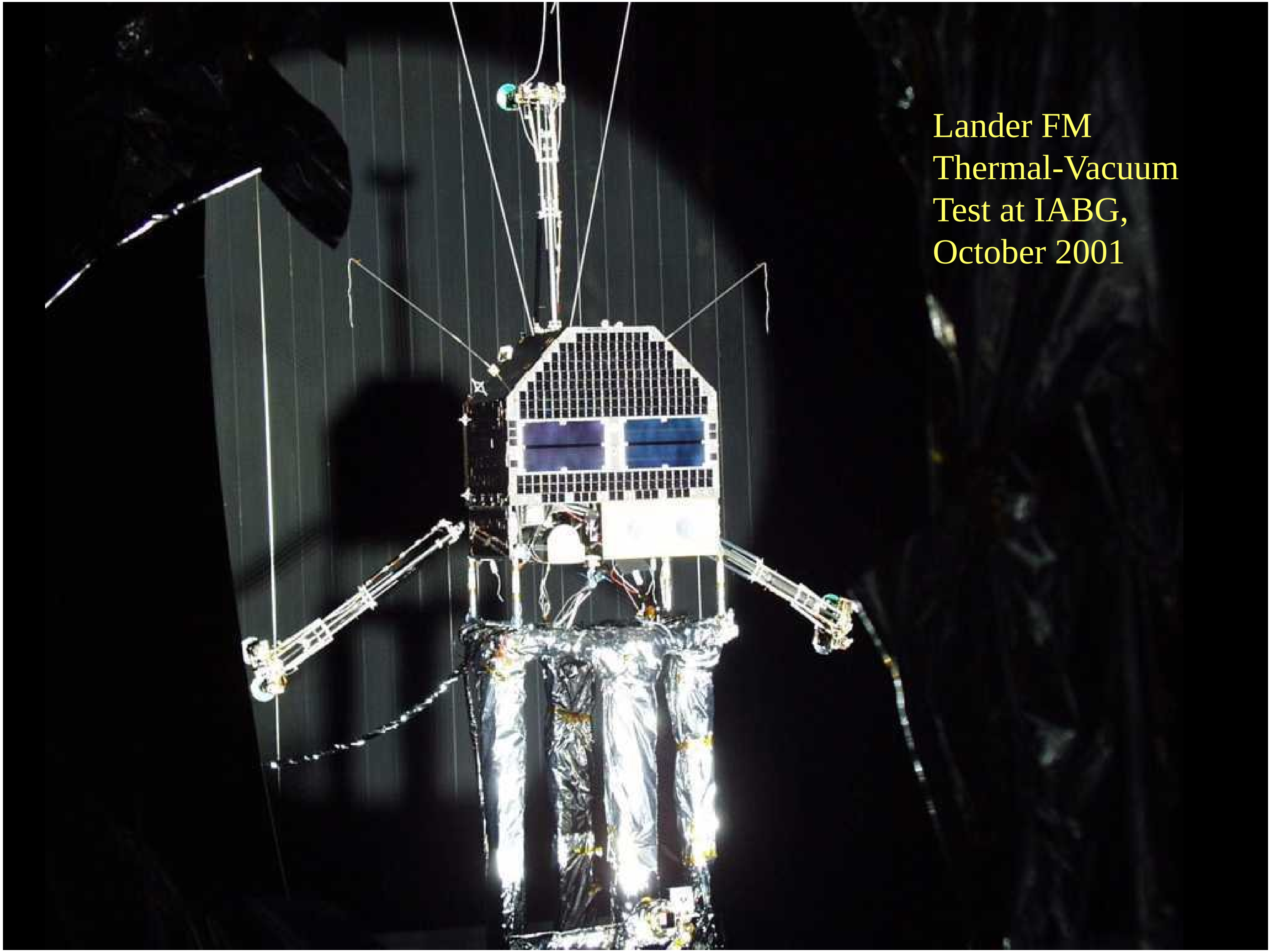
Mission

- Cruise: 10 years
- SDL (Descent) 30 .. 60 min: Images, magnetic field, acoustic and IR mapper calibration, dust impact
- First science sequence: feasible only with primary battery, core science, lasts about 55 hours
- Longterm mission: ~3 months (until r<2 AU resp. overheating): very interesting variations with day/night cycle and approach to the sun /activity variations

Rosetta Trajectory

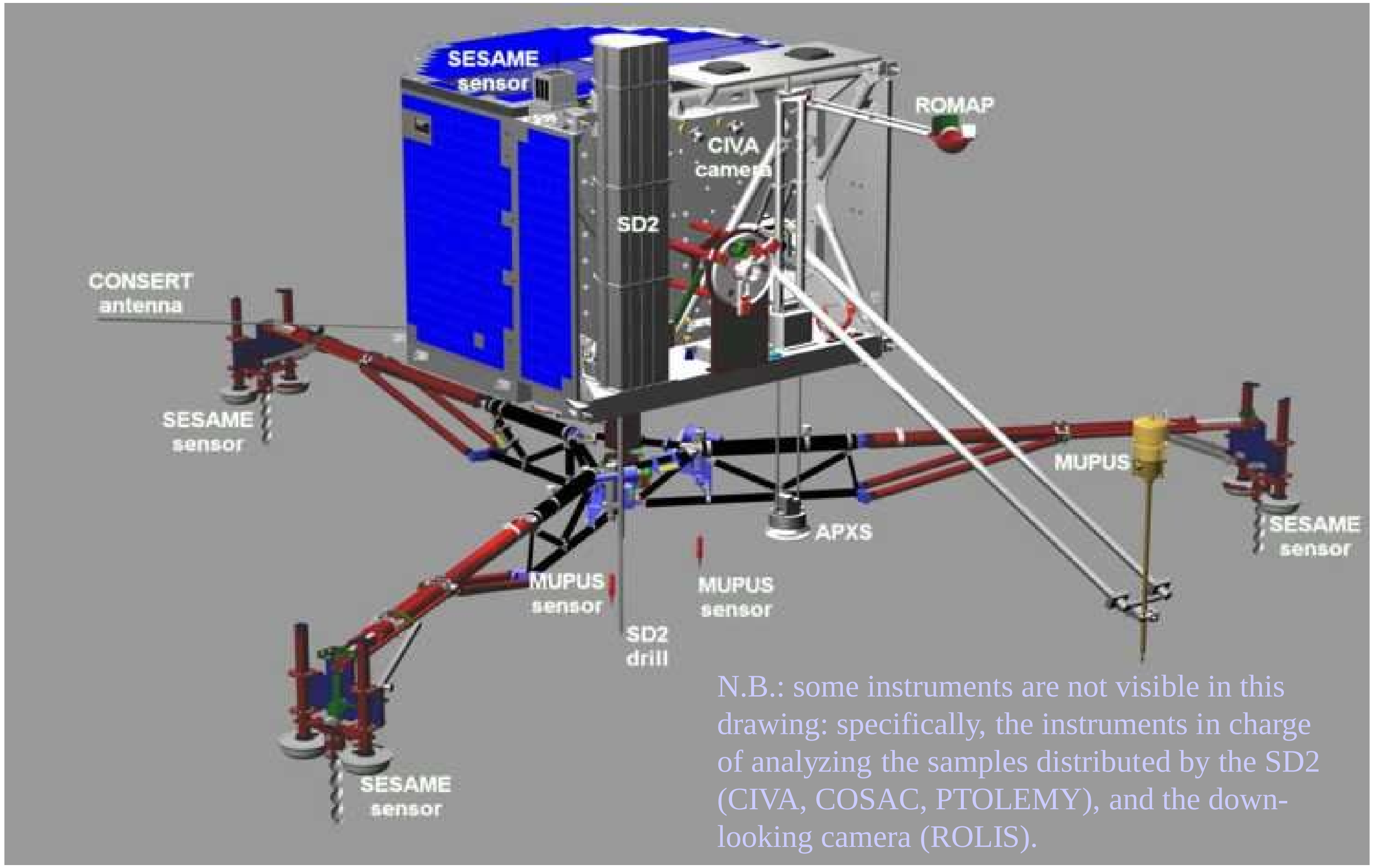



Space Science Department
REMOVE BEFORE FLIGHT



Lander FM
Thermal-Vacuum
Test at IABG,
October 2001

Schematic view of the Philae spacecraft



N.B.: some instruments are not visible in this drawing: specifically, the instruments in charge of analyzing the samples distributed by the SD2 (CIVA, COSAC, PTOLEMY), and the down-looking camera (ROLIS).

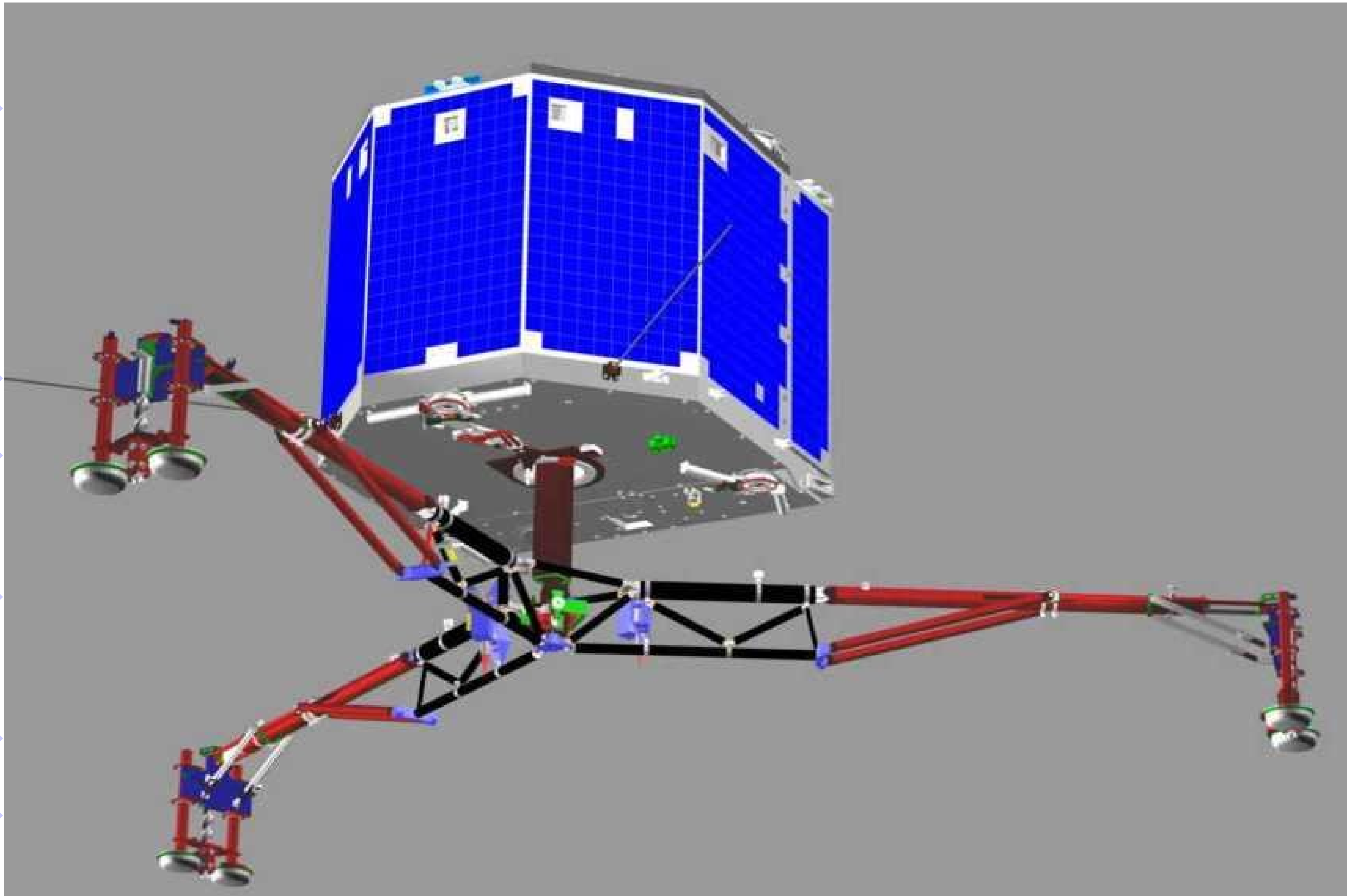
Scientific Objectives of the Lander

- In-situ-analysis of original material of the Solar System
  - Elemental and isotope composition
  - Organic molecules
  - Minerals and ices
- Structure and physical properties of the nucleus
  - Surface topology
  - Physical properties
  - Stratigraphy, global internal structure
- Observation of variations with time
  - Day-night cycle
  - Approach to the Sun

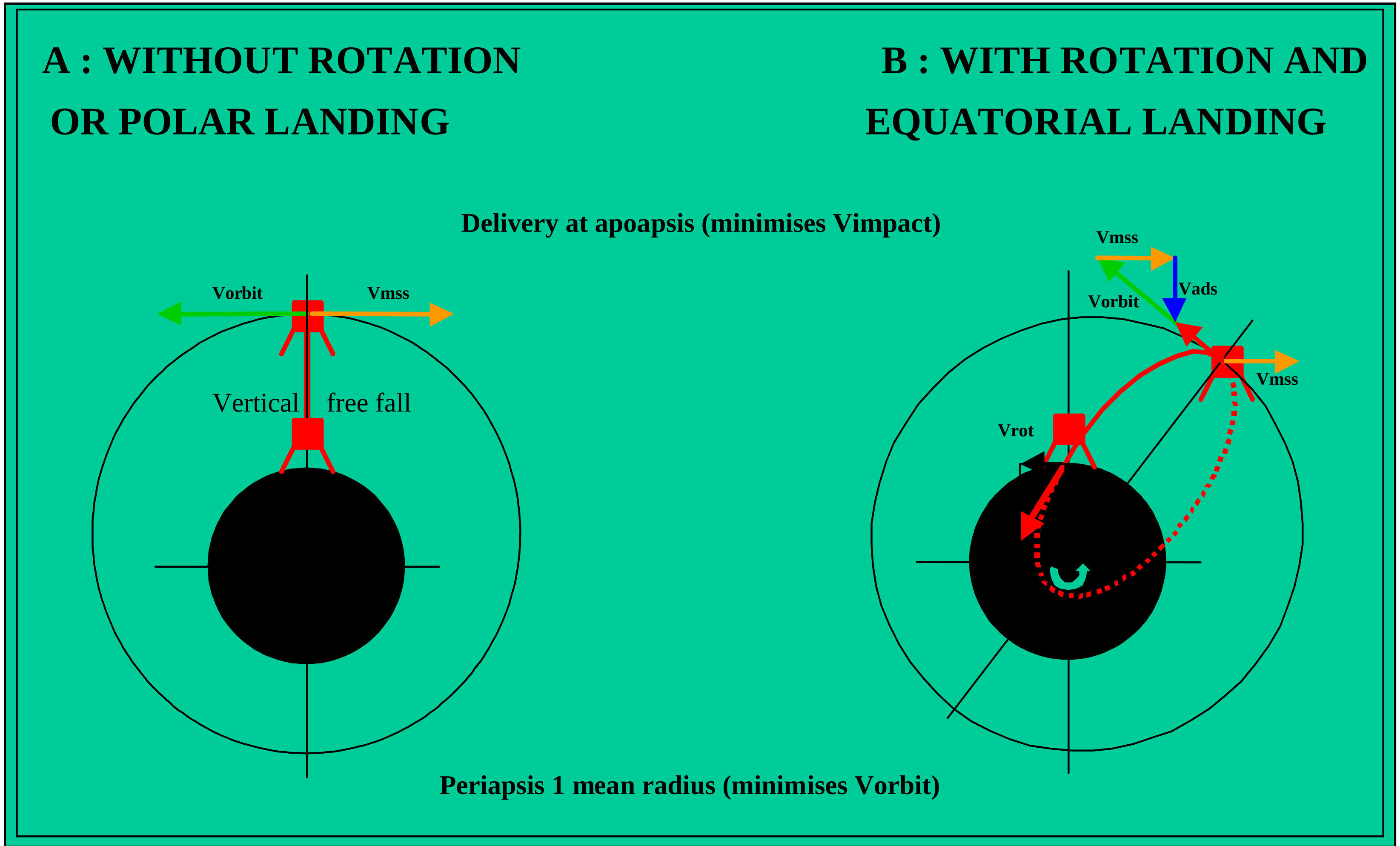
P/L Resources

- Mass: 22.01 kg, 26.68 incl. SD^2
- Power/Energy: currently about 52 - 65 hours of primary mission operation are feasible with ca. 30% system margin, long term mission relying entirely on solar cells thereafter
- Average power: 15-20 W with primaries, 10 W with solar power alone at daytime
- Data: 235 Mbit during primary mission, 65 Mbit during each subsequent 60 h period

Landing Scenario



Delivery Strategy

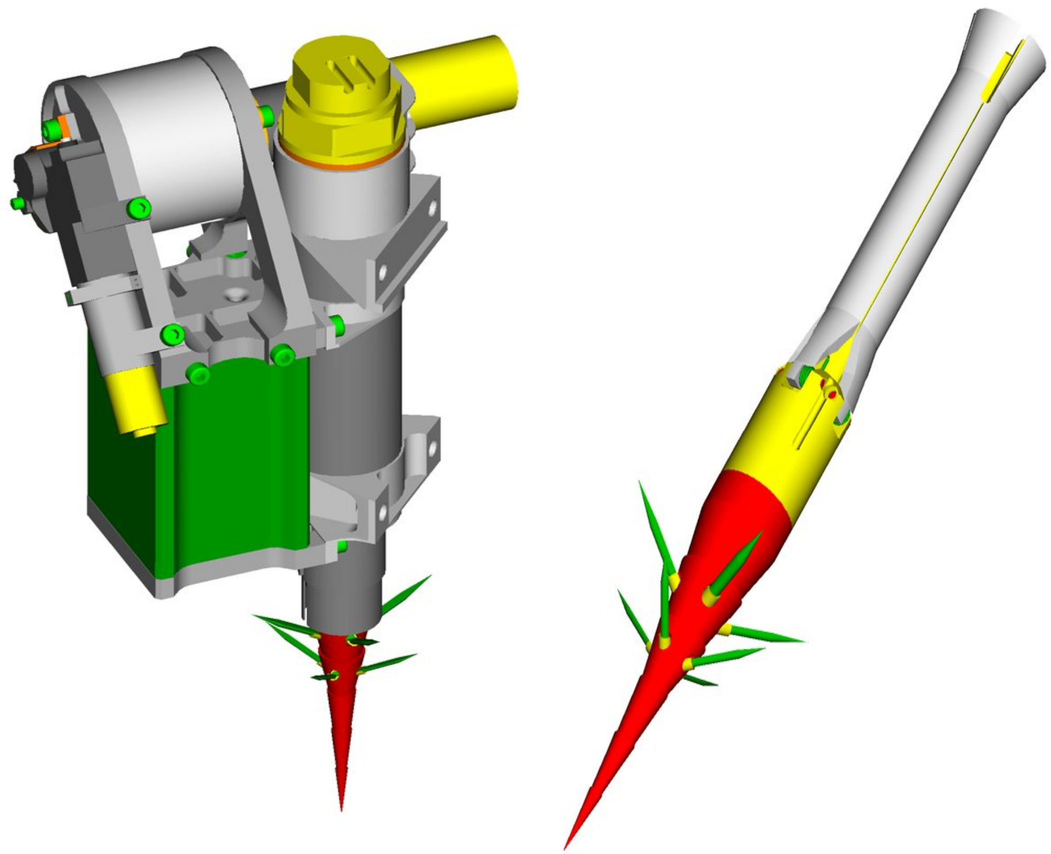


Harpoon Anchoring Device

2 harpoons, accelerated by a cartridge driven piston into surface material and con-nected by tensioned tether to the Lander´s landing gear.

Includes MUPUS accelerometers and temperature sensors

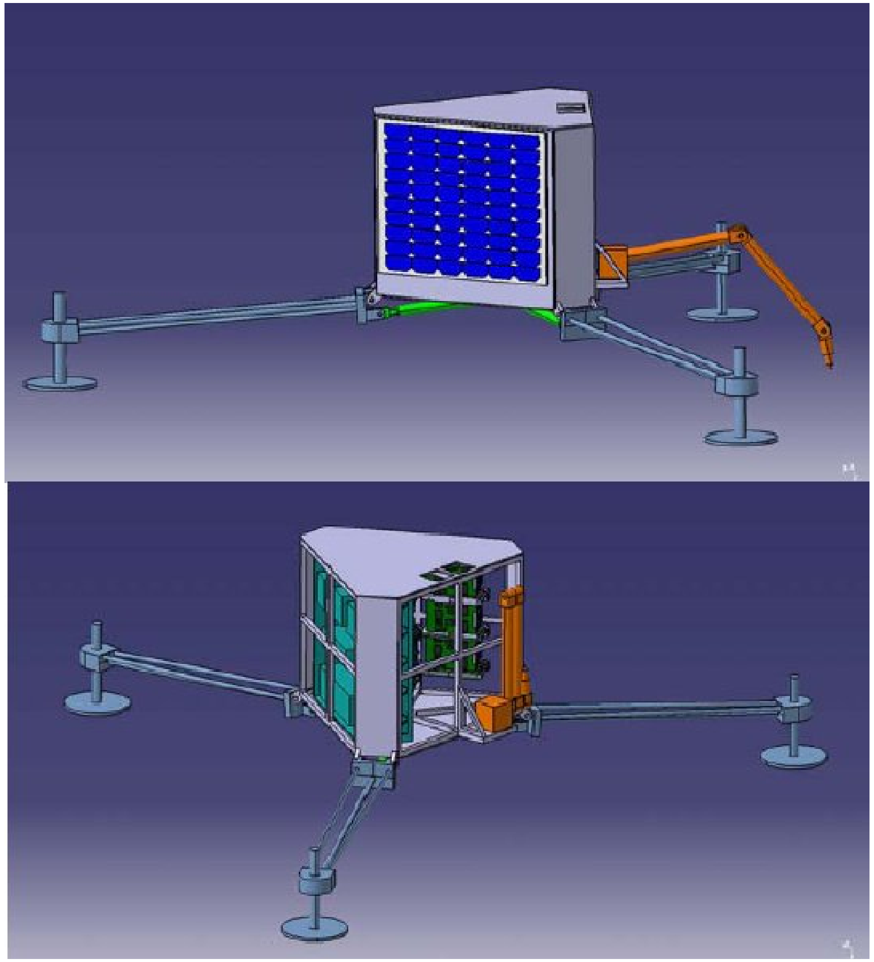
mass of unit:	**400g**
Projectile:	**100g**
rewind velocity:	**0.5 m/s**
anchor velocity:	**60 m/s**
rewind force(TBC):	**1...30 N**
max. tether tension:	**200 N**
max. gas pressure:	**250 bar**



Scalability of the Philae design

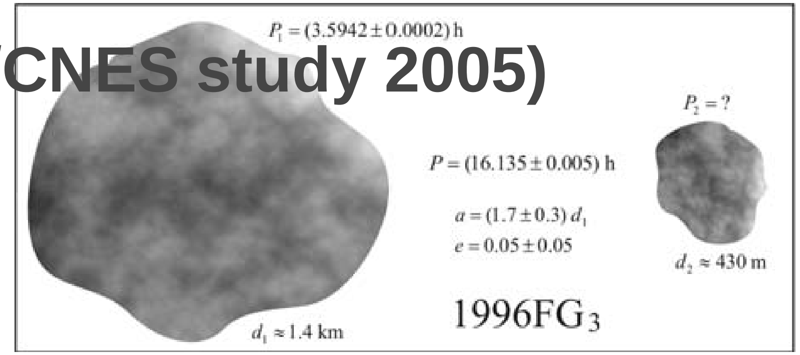
- The Philae design can be scaled in mass and size to some extent; internal DLR studies (Witte, 2009) show that similar landers for asteroids can be designed in a mass range down to about 40 kg and probably well beyond 150 kg. For very small systems (<< 50 kg), other concepts will be more adequate.

MASCOT – Lander (proposed for Marco Polo)



- A Lander, MASCOT, has been proposed, following the Instrument AO for Marco Polo but now foreseen for Hayabusa-2
- Several options (depending e.g. on the available mass 95- 70 -35- 10 kg) were studied
- A strawman payload has been suggested:
  - Ion Laser Mass Analyser
  - Evolved Gas Analyser
  - APXS
  - Mößbauer Spectrometer
  - Camera Systems (incl. microscope and IR spectrometer
  - ATR
  - Mole – Penetrator
  - µ-Seismometer
  - Tomographer Radar instrument

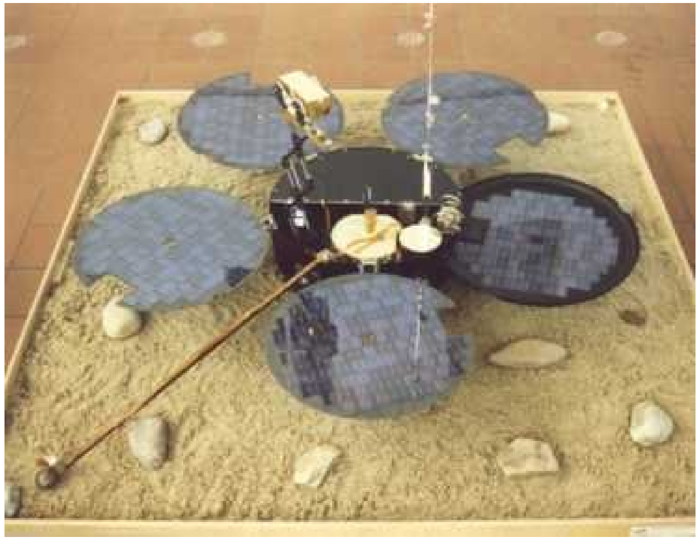
A 30 kg „shell Lander“ (DLR/CNES study 2005)

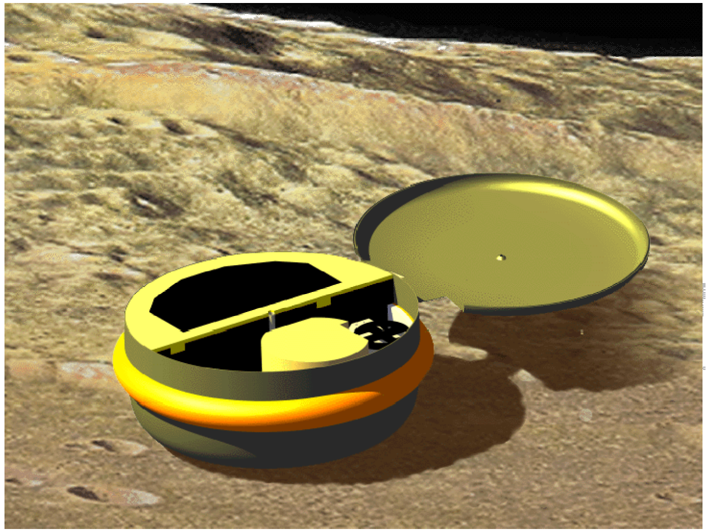


- NEO mission to 1996FG$_3$
  - Landed mass = max. 31 kg incl. margins
  - 0.7 – 1.4 A.U. sun distance, Asteroid diameter 1400 m, bulk density 1100 – 3000 kg/m^3, rotational period 3.6 hours

  $\rightarrow$ Vertical touchdown velocity < 1 m/s
- For a 7.3 kg payload (incl. margins) two options are feasible:
  - either a battery-driven lander with a lifetime of approx. 5 days, or
  - a solar-generator powered lander with a long lifetime (≥ 2 months).
- Total lander mass is 31 kg, 20% margins are included on each subsystem.
- As most components of the lander system rely on Netlander phase B developments or Philae FM parts, the design should be quite robust.
- Delivery is straightforward, as there is no attitude control required.
- Upon touchdown, two harpoons will anchor the lander and operations can be started. Instruments are assumed to be integrated primarily on the RSS.
- Thermal system design (large temperature amplitudes, 2:1 changes in solar insulation!) based on Philae heritage.

NetLander Heritage for an Asteroid Lander

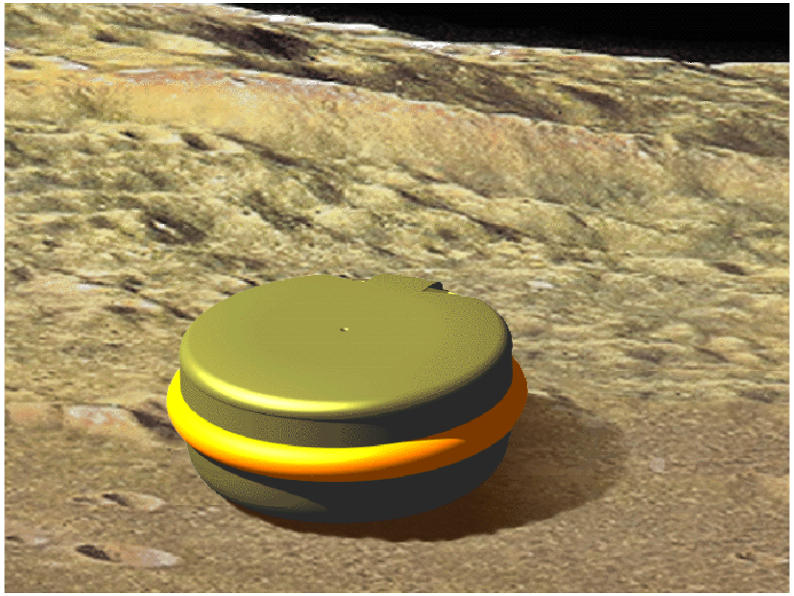


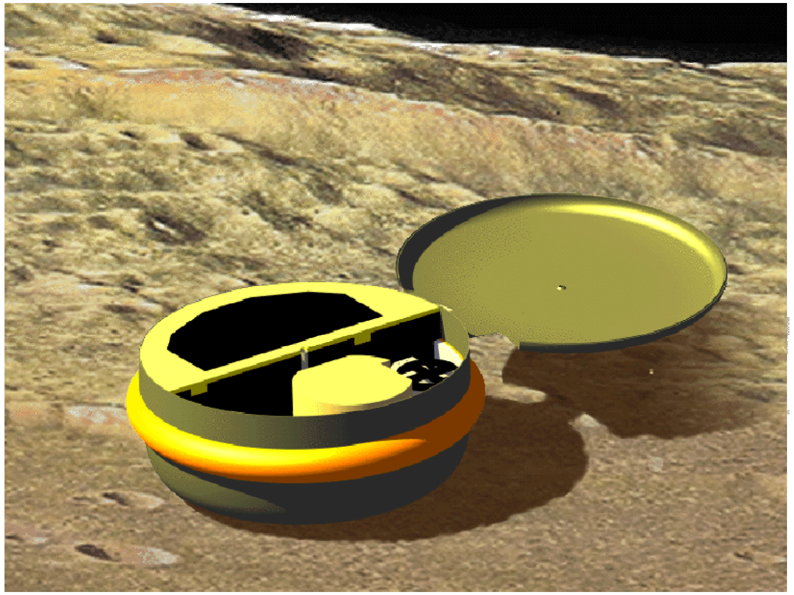


<u>Basic Approach:</u>

- **Use the developed mechanical platform of NetLander mainly as it is**
- **The 4 secondary petals under the main lid are removed (provided the Lander is battery-driven and does not need solar arrays)**

Landing in Upright Position

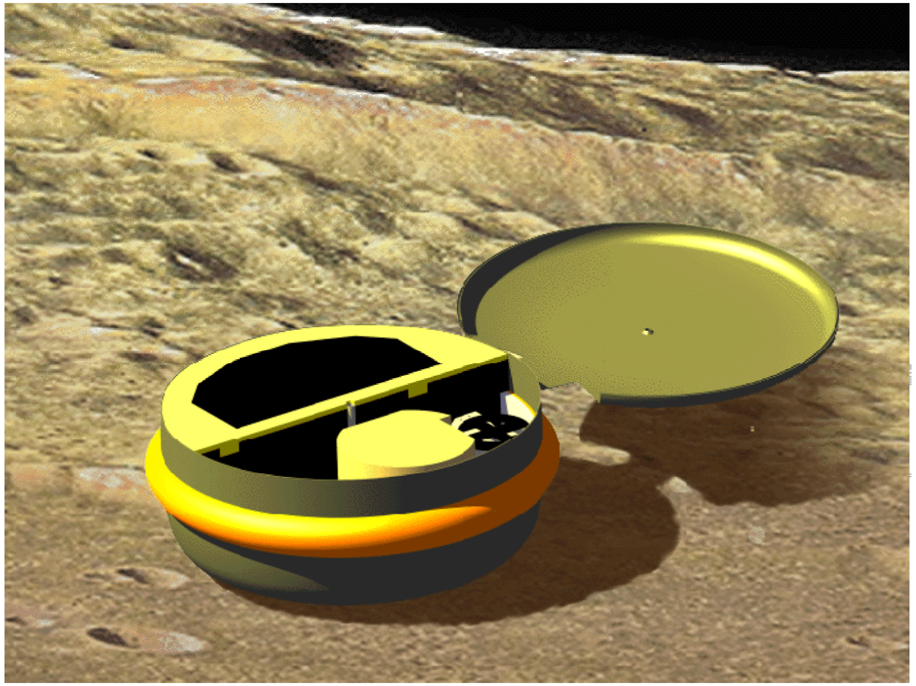




When the Lander has reached its final position (after all rebounces), the lid is slowly opened and a circumferential hose is inflated.

There is no need to determine the Lander attitude by any sensors in advance. The operational configuration is reached automatically. The operational configuration (upright position with lid opened) can be safely reached from all landing scenarios.
Proper surface contact for the payload units is ensured.

Operational Configuration



The operational configuration (upright position with lid opened) can be safely reached from all landing scenarios.

Proper surface contact for the payload units is ensured.

Mobility concepts for small bodies
I. General

- Roving by wheeled vehicles is practically impossible
- Alternatively, surface elements could move with relatively low effort by means of propulsion systems (e.g., by cold gas thrusters)
- or using mechanically triggered jumping; the latter discussed in more detail hereafter. For landers without attitude control during descent, a self-rightening mechanism has to be foreseen for proper orientation on the surface after touchdown or after a mobility operation.

PROP-F, the Phobos hopper

- 45 kg hopper on the Russion Phobos-2 mission (1988)
- 1-2 km altitude drop over Phobos surface, no attitude control, impact with 5 m/s dampened by „pacifier“
- Self-righening (see below), hopping: with „whiskers“ , spring tensioned by motor.
- Operations time was limited to about 4 hours and a maximum of 10 jumps (driven by the capacity of the battery, 30 Ah)

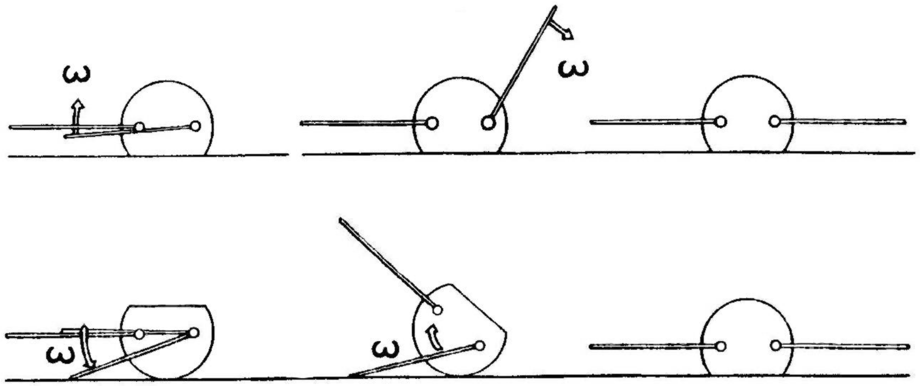
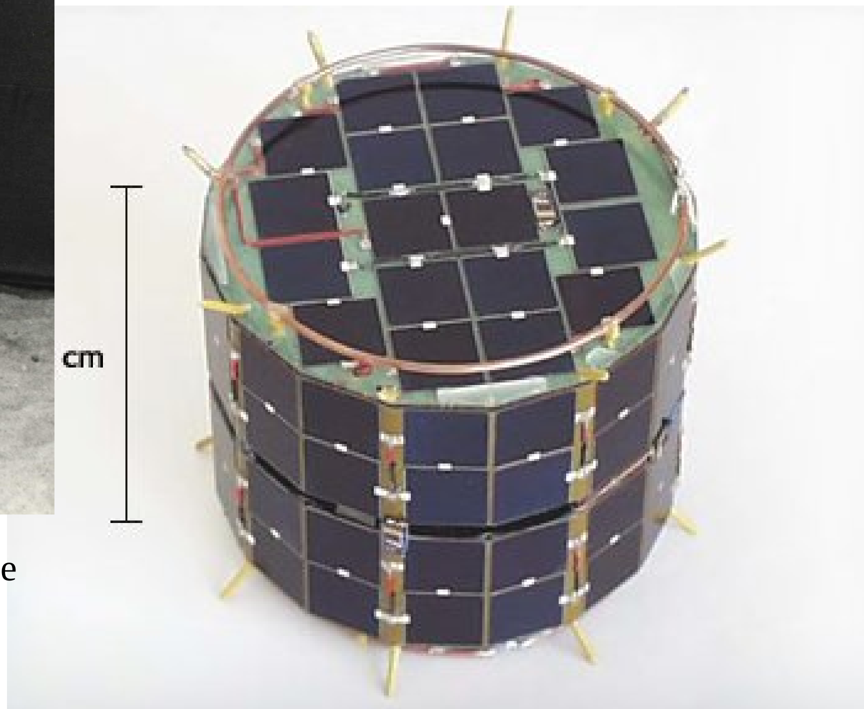


Image courtesy VNII Transmash

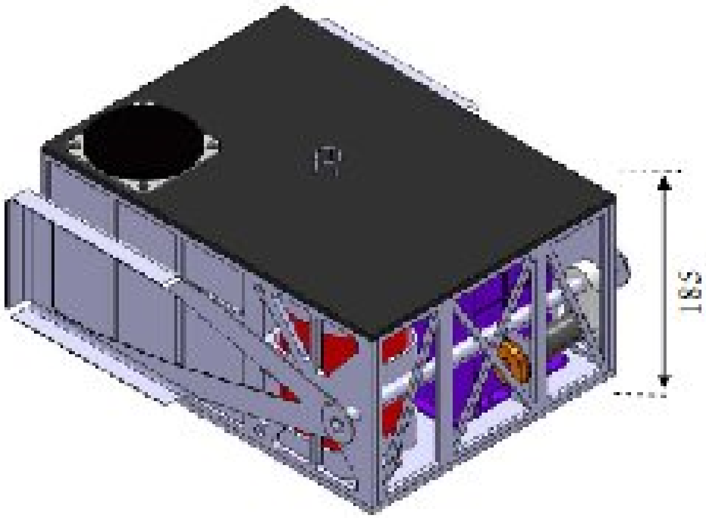
The tests of the orientation mechanism of the mobile probe with simulated Phobos gravity (courtesy VNIITransmash)

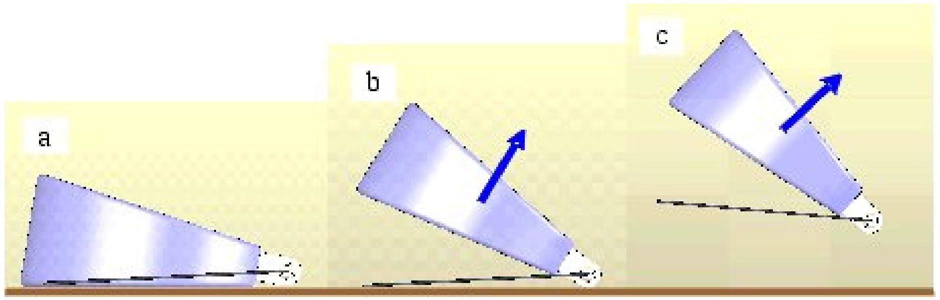
- Minerva: 0.6 kg robot on Haybusa-1
- Long-lived, excenter mass uncontrolled hopping



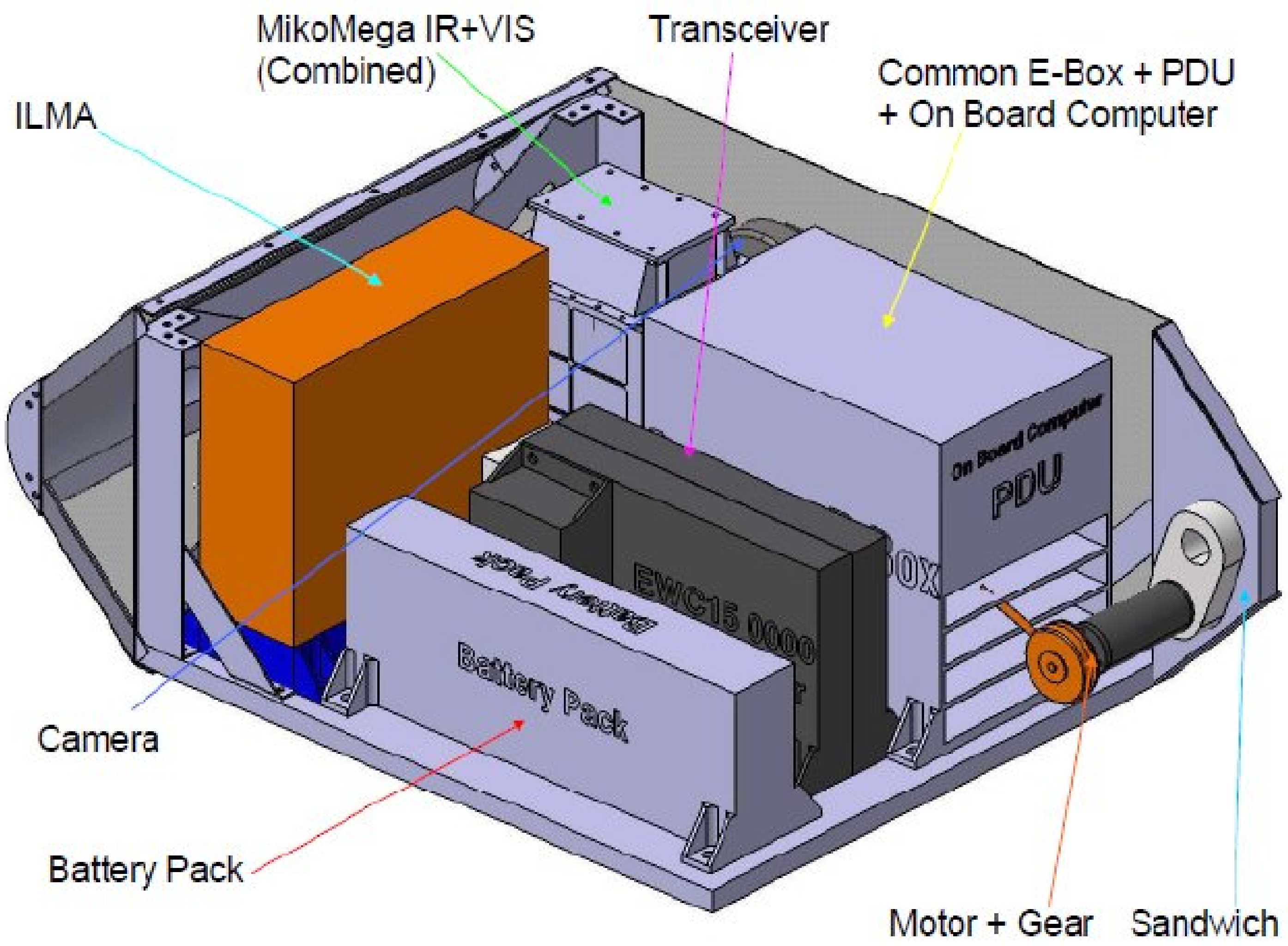
Mobility concepts for small bodies
II. Developments for future missions

- Mascot XS hopper (see Caroline Lange et al. Presentation!) inititally with „whiskers“ or „arms“
- A slightly different concept of mechanically triggered jumping includes accelerating masses inside the lander body. Depending on the parameters, turning or hopping can be achieved. These concepts are presently under intense investigation in the context of the MASCOT project at DLR.
- 10-15 kg range, 300x300x185 mm^3, Payload mass 3 kg
- Scaleable: certainly bigger hoppers are feasible!





MASCOT XS



MikoMega IR+VIS
(Combined)
Transceiver
Common E-Box + PDU
+ On Board Computer
ILMA
On Board Computer
PDU
EWC15 0000
Battery Pack
Camera
Battery Pack
Motor + Gear
Sandwich

MASCOT XS characteristics

- Hopping distance order of 100 m, time 0.5 h, depending on attitude and latitude for a given asteroid (Trot, size).
- Lifetime ~15 hours (batteries only)
- Solar generator option is not heavier, but more complex (deployable petals, more complicated thermal system, operational constraints)

60 deg, jumping in direction of (nearest) pole -> best case				
starting point		distance	max. altitude	duration
equator (latitude 0 deg)	longitude 0 deg, r = 460 m	69.2 m	31.6 m	1515 s (25 min)
	longitude 90 deg, r = 390 m	45.4 m	20.8 m	974 s (16 min)
latitude 45 deg	longitude 0 deg, r = 423 m	53.2 m	29.4 m	1284 s (21 min)
	longitude 90 deg, r =373 m	37.8 m	19. 8 m	881 s (15 min)

Conclusions

- Landers on Comets or Asteroid allow essential measurements, even in case of a Sample Return Mission
- There is significant heritage in Europa for the development of Small Bodies Landers; in the range between ~10kg and >100 kg
- Several Missions to small bodies are currently studied (e.g. Hayabusa-2). All of them could/should include Landers

Additional material

Structure

- Manufactured in High Modulus Carbon Fibre (DLR Braunschweig, Institute for Structural Mechanics)
- Consists of
  - Baseplate
  - Experiment Carrier
  - Hood
  - Struts + Support Elements
- Conductive Cover on outer Surfaces

Drill and Sampling Device SD^2

•SD2 manufactured by Tecnospazio, Milano under ASI contract

•Drill depth up to 230 mm

•drill-collect-transport to carousel-volume checker - rotate carousel and present for analysis

•Mass 3.6 kg

•Power 5 to 12 W

Missions and Studies

- Phobos (1988-1989)
  - Included long term Lander and Hopper
  - Mission failed during approach
- NEAR (1996 - 1997)
- Rosetta Lander (2004 – 2014)
  - Philae (on ist way to Churyumov-Gerasimenko)
  - Concepts for smaller Landers: RoLand and Champollion
- Hayabusa (2003)
- Deep Impact (2005)
- Phobos Grunt (2009 tbc)
- Leonard (CNES-DLR-ASI study)
- Marco Polo (ESA/(JAXA) Cosmic Vision study)
- MASCOT (DLR-CNES-JAXA, ongoing)

Mass breakdown

Unit	Mass [kg]
Structure	18,0
Thermal Control System (/MLI)	3,9 (/2,7)
Power System (/ Batteries / Solar Generator)	12,2 (/8,5/1,7)
Active Descent System	4,1
Flywheel	2,9
Landing Gear	10,0
Anchoring System	1,4
CDMS	2,9
TxRx	2,4
Common Electronics Box	9,8
MSS (on Lander), Harness, balancing mass	3,6
Payload	26,7
Sum [Lander]	97,9
ESS, TxRx (on Orbiter)	4,4
MSS, harness	8,7
Sum [incl. Orbiter units]	111,0

PHILAE, THE ROSETTA LANDER: the target is almost unknown

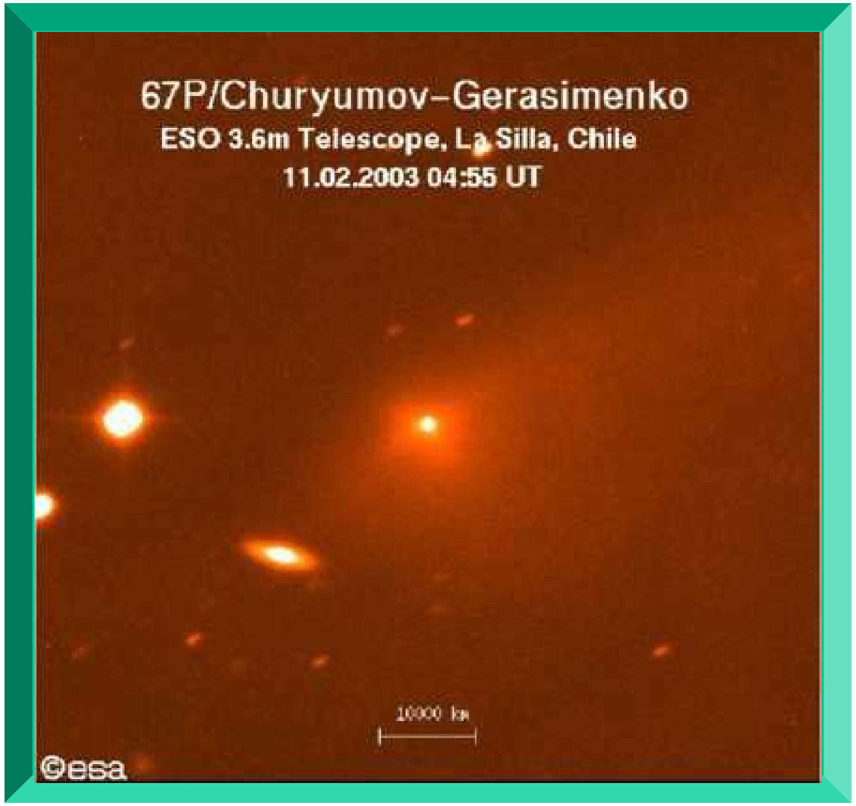
- Engineering models for the comet surface properties covered a range for the compressive strength between 60 kPa and 2 MPa. The surface roughness is completely unknown. Extreme surface compressive strengths down to a few kPa are now covered as well.
- The results of space missions to various asteroids and comets indicate that these bodies show a very wide range of surface characteristics and are very different to each other.

Technical Challenge developing Philae (and merging two smaller Landers both proposed for Rosetta)

- Soft Landing on a Comet -
  Nobody has tried this so far... How soft is the comet, anyway?
- Size, mass, day-night period, temperature and surface properties of the comet are only vaguely known
- Longterm Operations of a Lander in Deep Space without RTG´s
- 10 Science Instruments aboard a 100 kg Lander

Target: Comet 67P/Churyumov-Gerasimenko

Discovered by Klim Churyumov in photographs of 32P/Comas Solá taken by Svetlana Gerasimenko on 22 October 1969.



- Characteristica:
  - Diameter ~4000 m
  - Density 0.2-1.5 gcm^{-3}
  - Aphelion 5.75 AU
  - Perihel 1.3 AU
  - Orb.period 6.57 years
  - Albedo ca. 0.04
  - Rotation 12,7 h
- latest Perihel: 2009 Feb 28

Contribution of Philae to the Orbiter Science

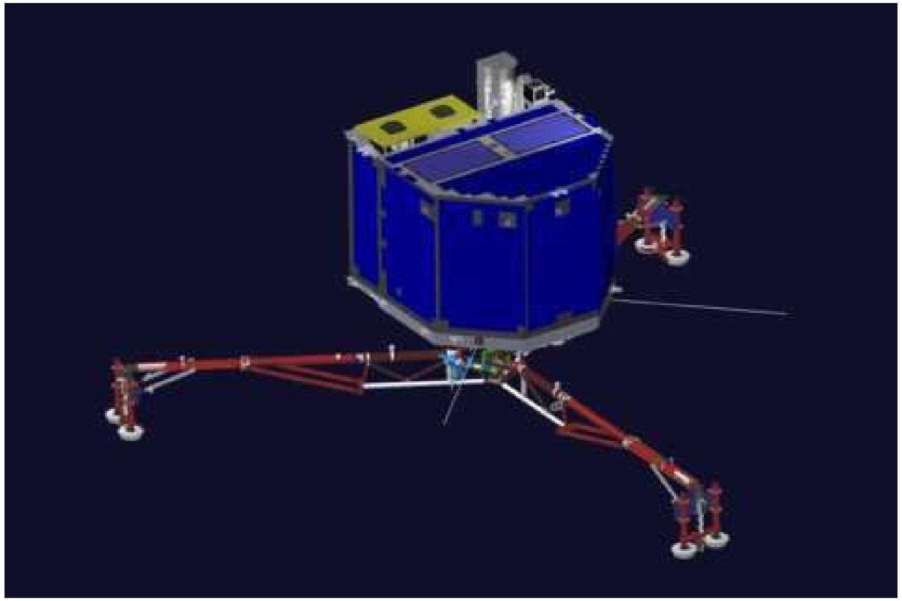
- Phenomena which are not observable remotely by the Rosetta Orbiter:
  - local erosion of the surface by sublimating ices, modifications of texture and chemical composition of near surface materials, changes in dust precipitation and heat flux through the surface, which is the determining parameter for all processes modifying cometary material.

- CONSERT
- Seismometry and magnetometry will also be used to investigate the interior of the comet.

- Local ground truth to calibrate Orbiter instruments.
  - Calibration of albedo and topographical features observed by the Orbiter camera.
  - In-situ chemical and mineralogical analysis of surface material by the Lander payload provides a means to correlate chemical and mineralogical compositions with brightness at various infrared wavelengths observed by the Orbiter.

Lander Characteristica

- Landing system
  - Damping of landing
  - Rotation and hight adjustment
  - Anchoring with harpune
  - „Hold-down Thruster“
- Energy- und Thermal-Concept
  - Solar generator 11 W (at 3AU)
  - Primary and secondary batteries
  - „warm“ and „cold“ areas
- Drill /Sampling Device
  - Drill depth 20 cm
  - multiple sampling
  - low temperature modifications
- Data
  - Central computer
  - Data relay via Orbiter (16 kb/s)



The Consortium

System contributions

- DLR (Köln, Braunschweig)
- MPG (Lindau, Garching)
- CNES (Paris, Toulouse)
- ASI (Rom, Matera)
- KFKI (Budapest)
- TU-Budapest
- STIL (Maynooth)
- FMI (Helsinki)
- RAL (Chilton)
- IWF (Graz)
- ESA

Instruments

- MPG (Lindau, Mainz, Garching)
- IAS, Orsay
- DLR (Köln, Berlin)
- Open University (Milton Keynes)
- KFKI (Budapest)
- FMI (Helsinki)
- Universität Münster
- CEPHAG (Grenoble)
- Politecnico Milano

Scientific Instruments

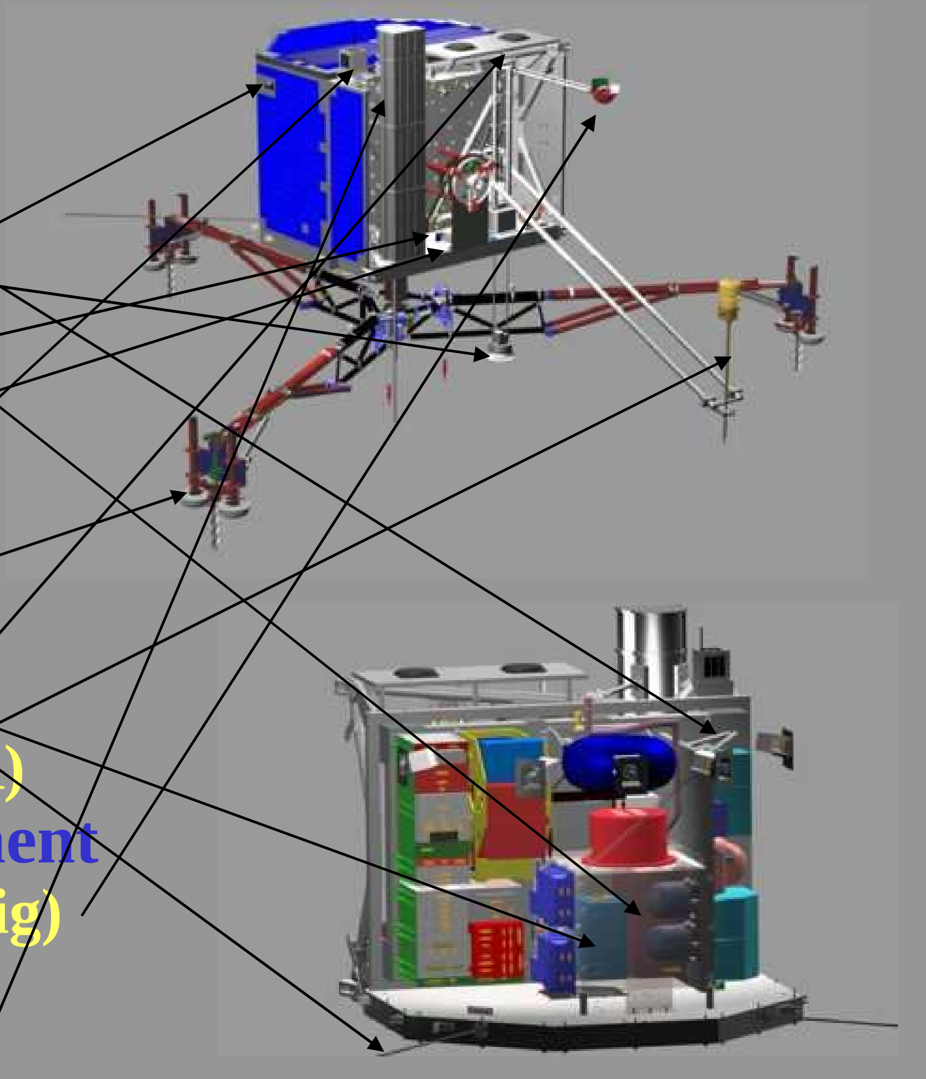
Material Analysis
- COSAC (MPS)
- MODULUS (OU)
- APX (MPCh/Uni Mainz)

Cameras
- ÇIVA (IAS)
- ROLIS (DLR)

Structure
- SESAME (DLR)
- CONSERT (LPG)
- MUPUS (U. Münster/DLR)

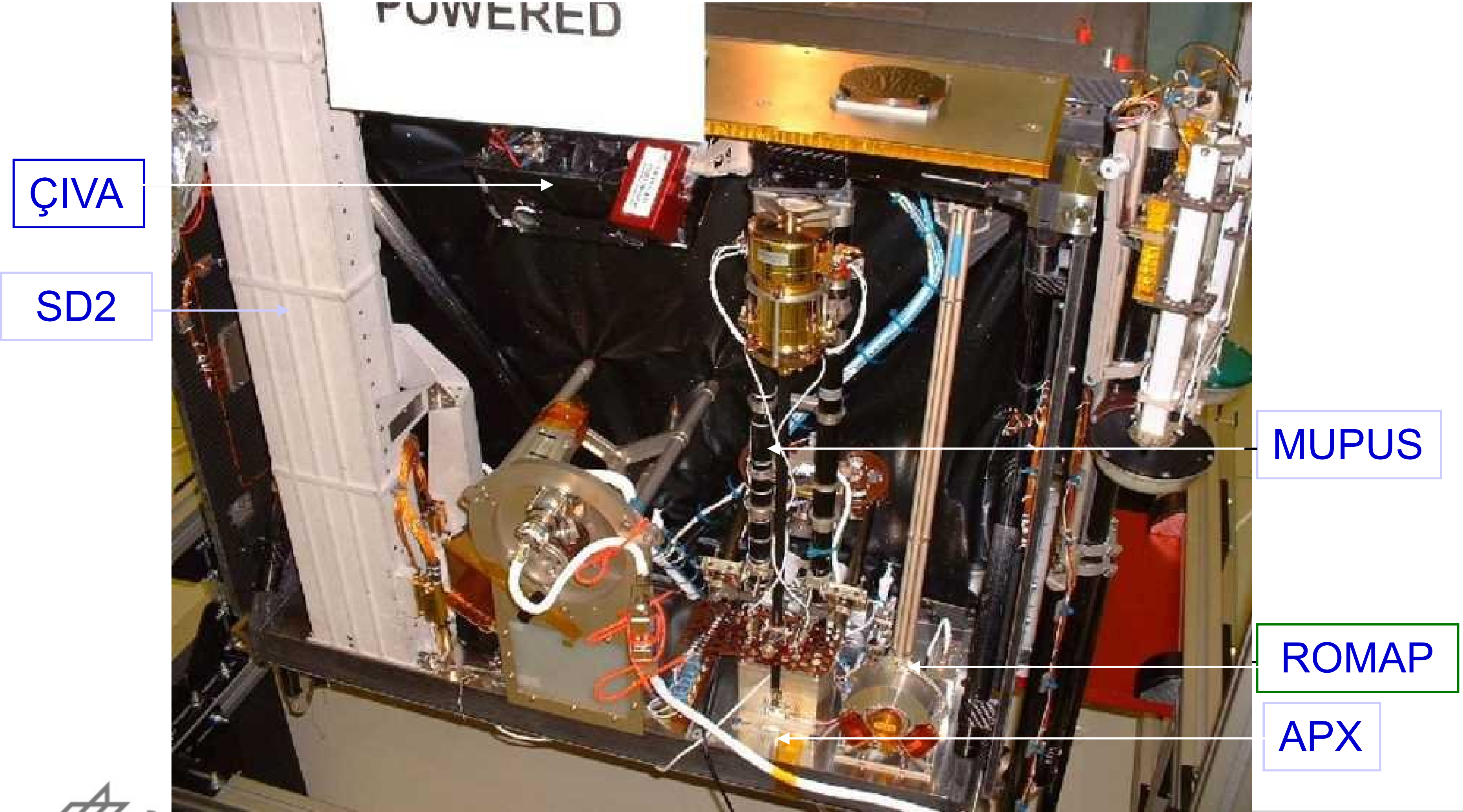
Plasma/Magnetic Environment
- ROMAP (TU Braunschweig)

Sampling & Drilling Device
- SD^2 (Politecnico Milano)



Side view schematics of the inner structure of the lander compartment

Balcony payload („cold compartment")



Local Environment

Unknown topography and surface

Shape [km] about 3×5

Temperatures

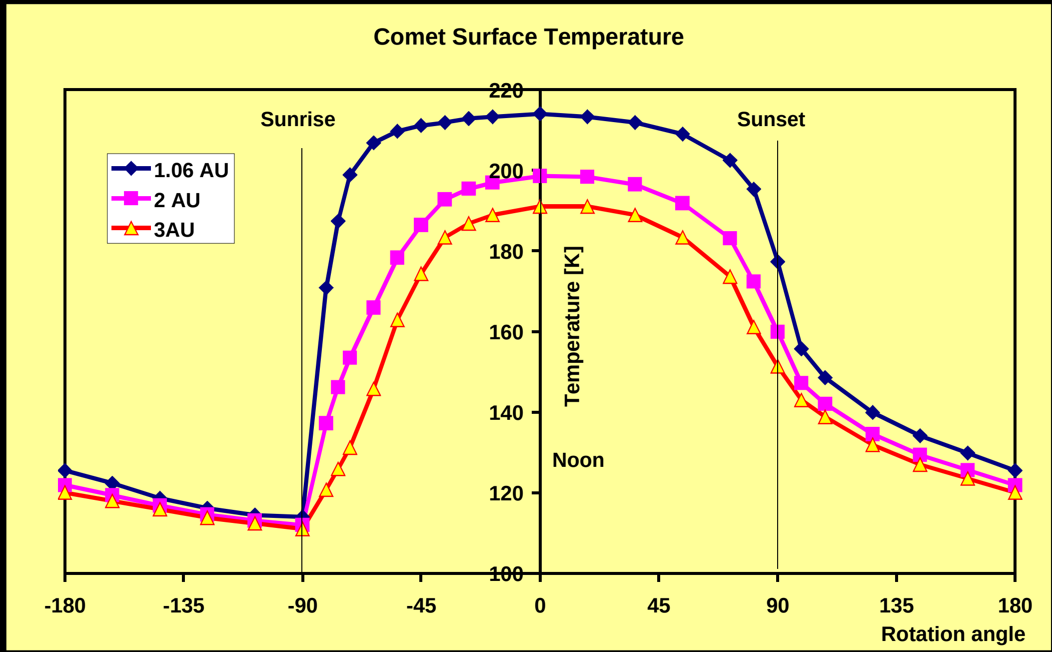
Day ~ -80 to 200 °C

Night > -160 °C

Rotation period 12,3 h

Surface strength:
1 kPa to 2 MPa (??)

Gravity ~10^{-4} g



Implications of Change of Target Comet

(from Wirtanen to CG)

- Increased Mission Time
  - Experimenters need to live even healthier.... landing in 2014
- Churyumov-G. is considerably bigger than Wirtanen
  - increased landing velocity
  - stiffened cardanic joint in landing gear
  - iterated requirements regardind separation altitude (>1km)
- different dust environment
  - baseline landing still at 3 AU

SUBSYSTEMS

Thermal Control System

- Warm (-40°C) and cold (ambient cometary temperatures > -200°C) areas
- Solar absorbers on top panel
- Electrical power dissipation about 10W average
- No use of Radioisotope Heater Units (RHUs)

Power System

- Power to be provided with solar generators and by batteries.
- LILT solar cells (Si-based technology) 10-12 W @ day (3 a.u.)
- Li/$SOCl_2$-primary batteries (about 1000 Wh) Li-ion
- secondary batteries (about 140 Wh)
- Bootstrap procedure („wakeup“)

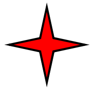
Telecommunications TxRx

- Telecommunication via Rosetta Orbiter, S-Band omnidir., redundant
- Data rate 16 kbit/sec
- Hard-coded TCs possible
- Blind commanding possible
- Max distance Lander-Orbiter: 150 km
- Highest Priority 1 week prior and 1 week after separation (with high fraction of visibility periods)
- Priority as Orbiter instruments during long-term operations

On-board computer: CDMS

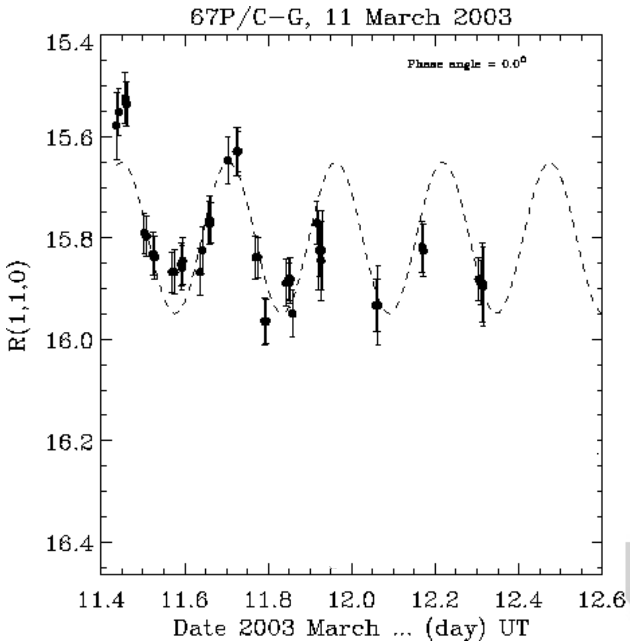
- Provides central computing and data storage capability (2x2 Mbyte, RAM, EEPROM)
- Acts as interface to the telecoms system
- Gouverns sequence of subsystem- and payload operations
- Provided by a Hungarian Consortium (KFKI Budapest, U Budapest)

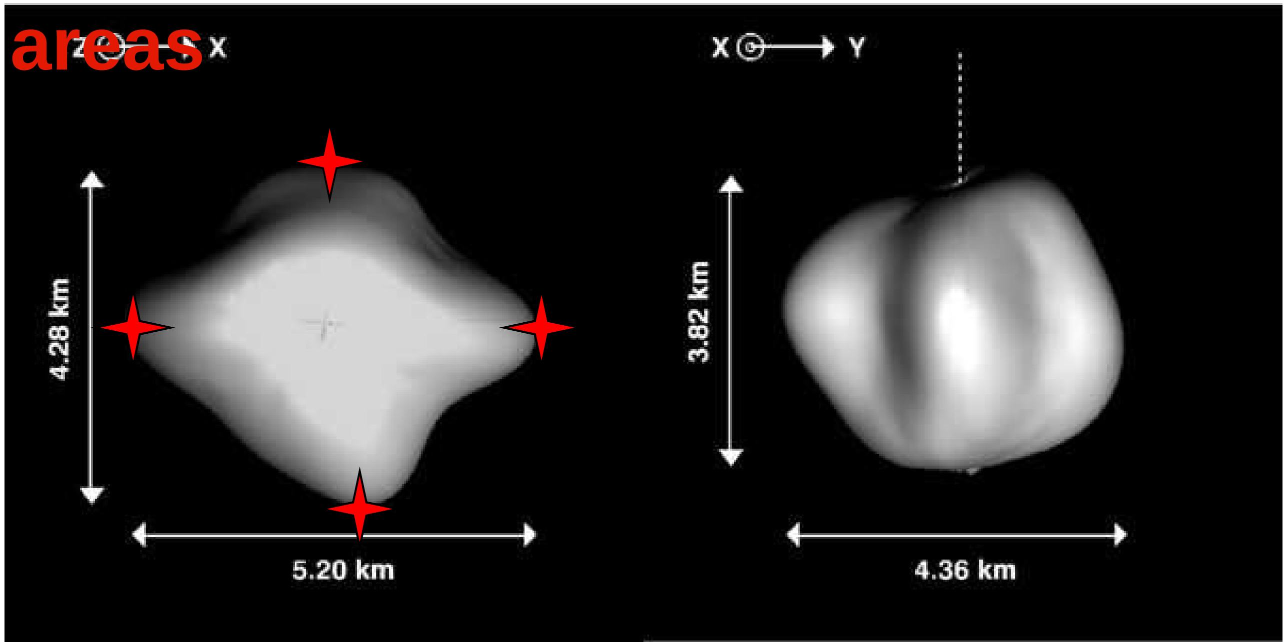
Shape, Landing areas

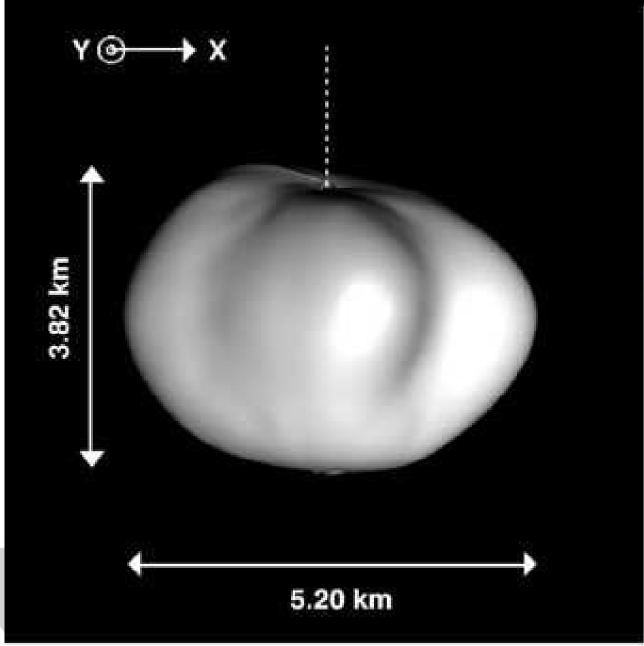


MOST FAVORABLE

LANDING AREAS







FROM THIS LIGHT CURVE DERIVED

FROM HST OBSERVATIONS

ON MARCH 2003 ,

THE P.LAMY TEAM MODELLED

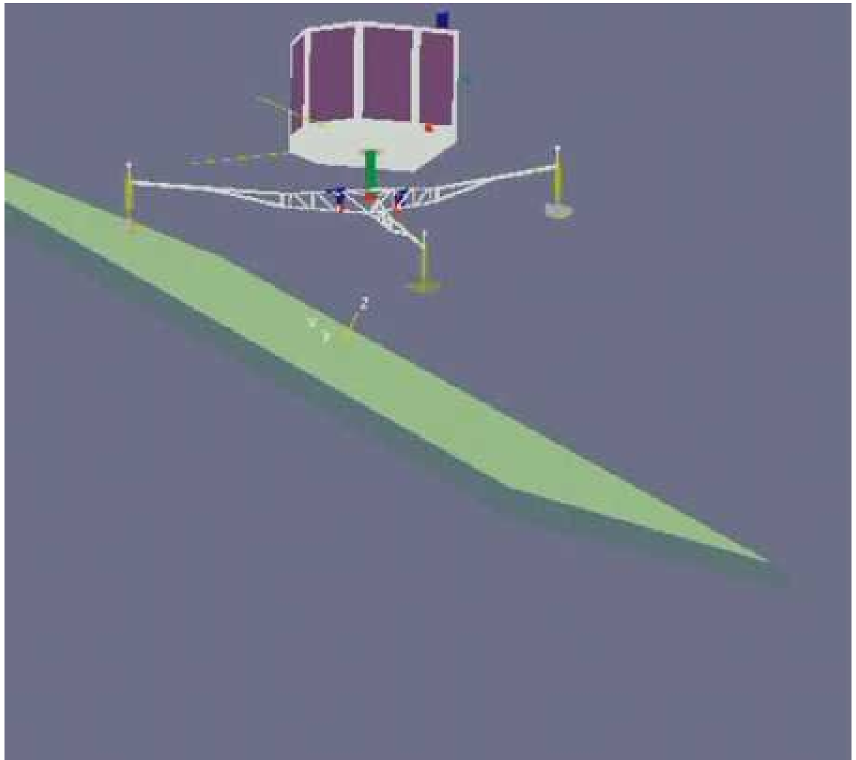
A POSSIBLE CG NUCLEUS SHAPE

(DPS 2003 presentation – CNES/NASA grant)

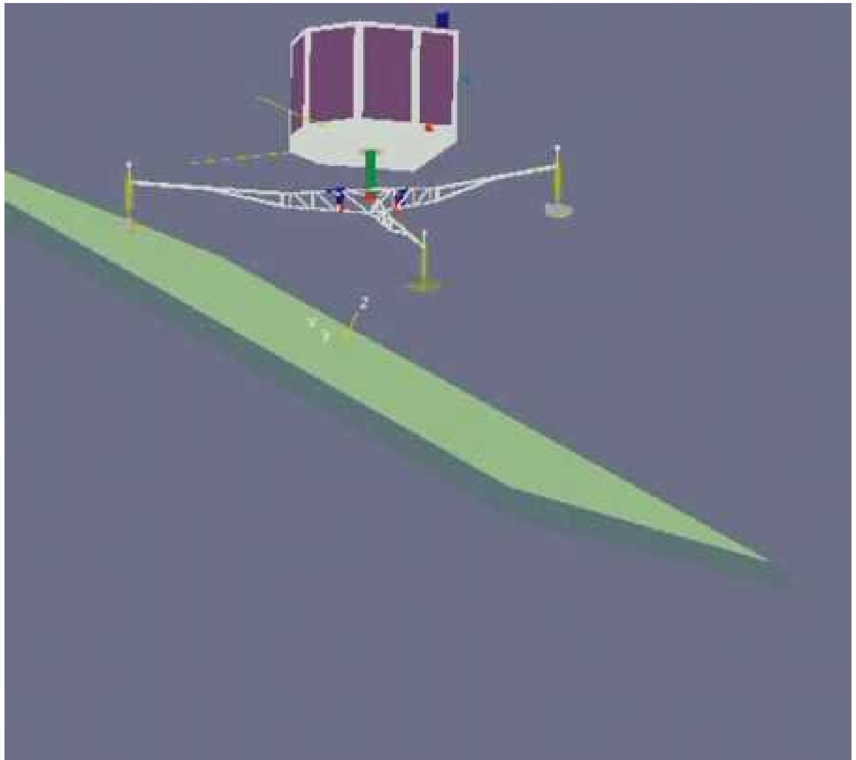
Landing strategy

- delivery foreseen in November 2014 at a distance of about 3 Astronomical Units (AU) to the Sun
- change of the target comet has a major impact on the Philae landing safety, since the expected touchdown velocity is much higher than in the case of P/Wirtanen (the original target of the Rosetta mission), due to the much larger size of P/Churyumov-Gerasimenko. Some hardware changes have been implemented, to increase robustness at touch-down. However, the safe landing remains highly sensitive to actual nucleus properties, largely unknown at this time.
- Consequently, a dedicated mapping phase will take place several months prior to separation, acquiring data from Orbiter instruments to update environmental and surface cometary models, towards an optimized selection of the landing site and of the release strategy.
- Following touch-down, Philae will have mission priority over Orbiter investigations for one week
- After this phase, Philae will share resources with the Orbiter investigations.

Touchdown Simulation



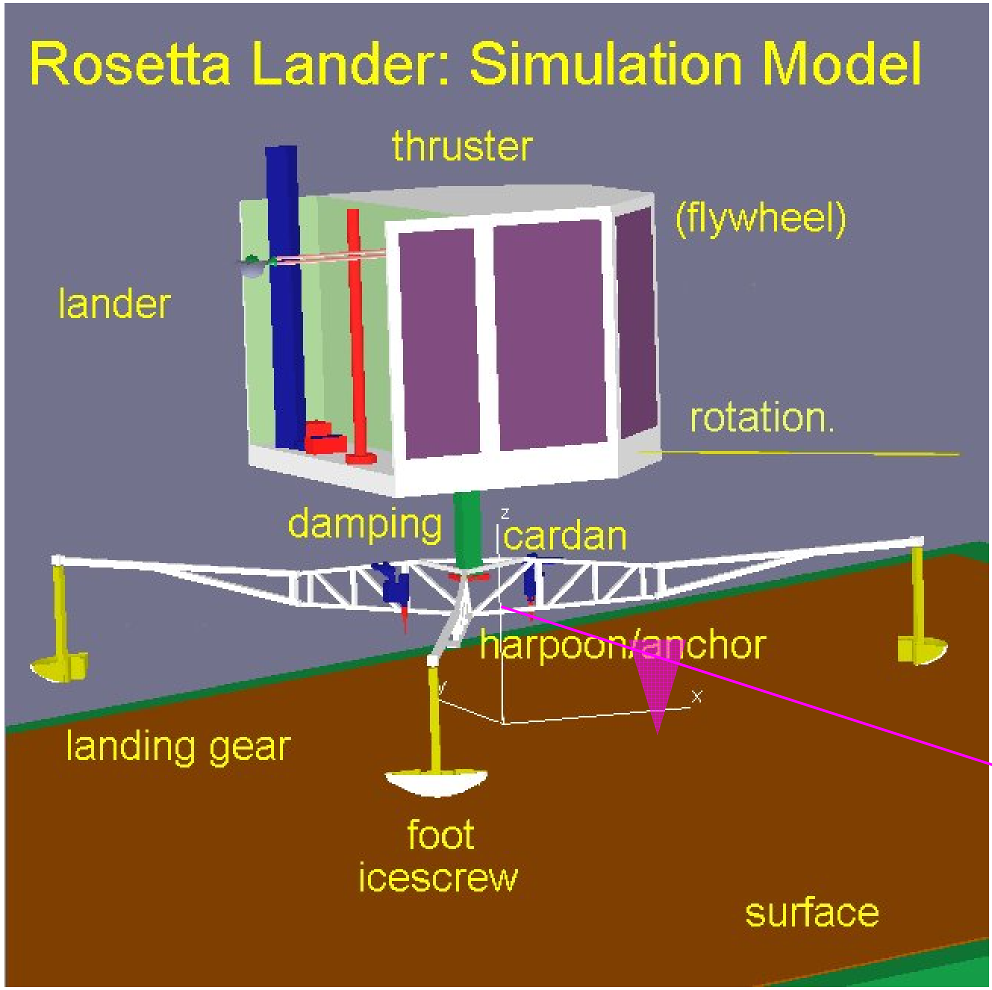
Free cardanic joint



Cardanic joint fixed to ± 5°

Landing with v_{impact} of 1.2 m/s at a local slope of 30°

Bubble rotation limitation simulation:

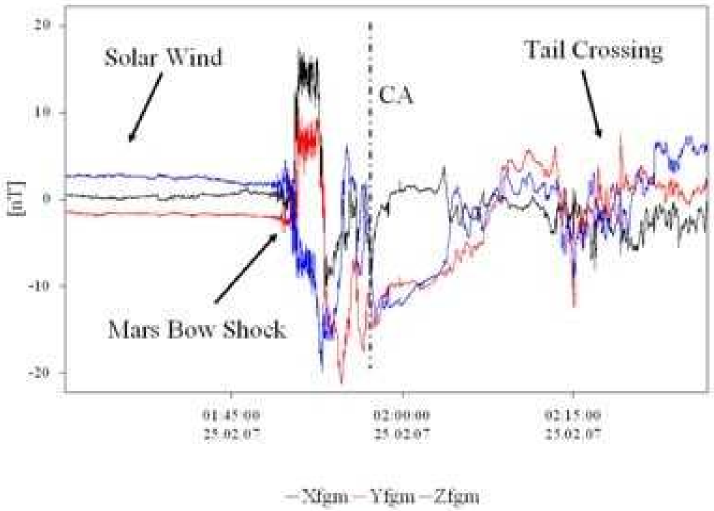


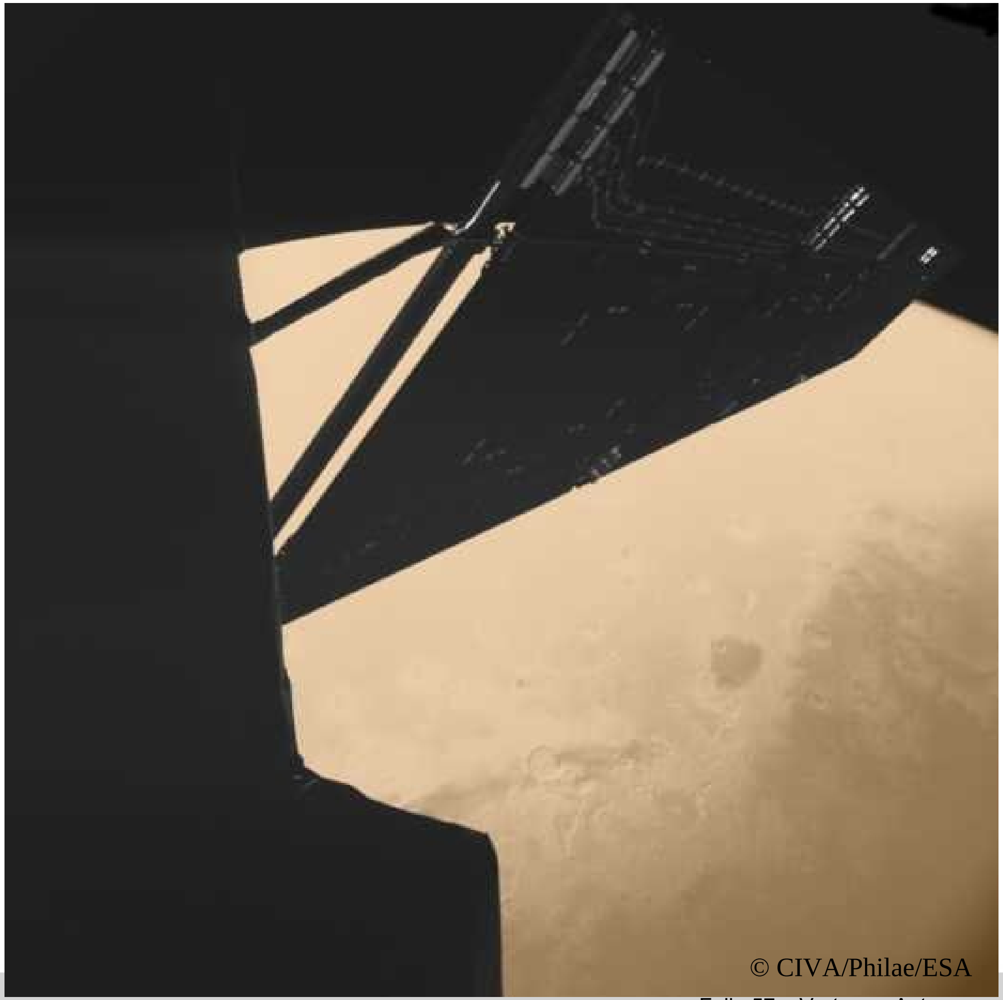
The bubble rotation is free for about 5°, 2.5° for the cardanic joint and 2.5° for the rotational torsion of the landing gear. The rotation is limited by a hard spring.

Cardanic joint

Mars Swingby 2007:   Some results

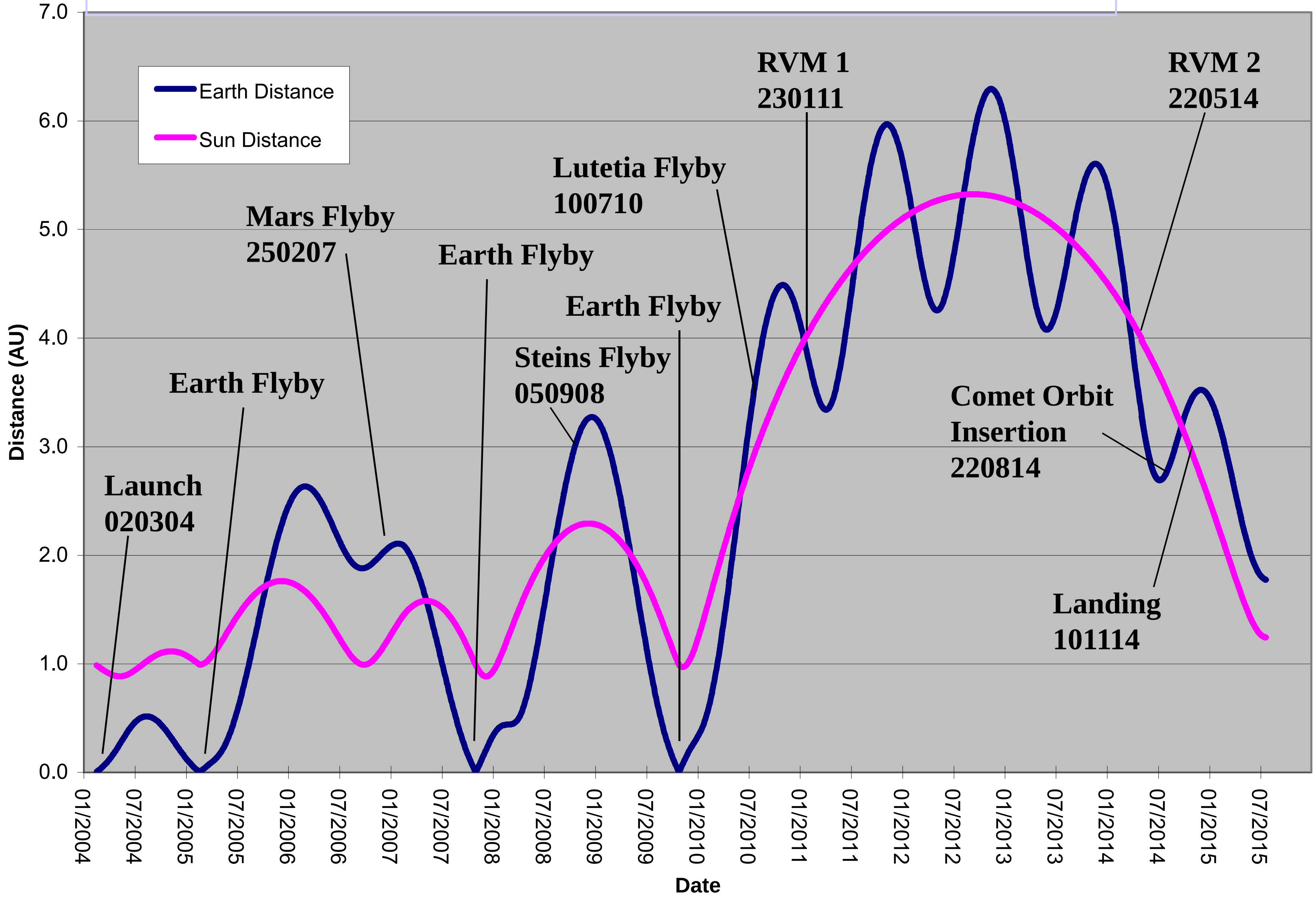
- Closest Approach: 250.6 km
- CIVA deliveres spectacular images
- ROMAP detects Bow Shock



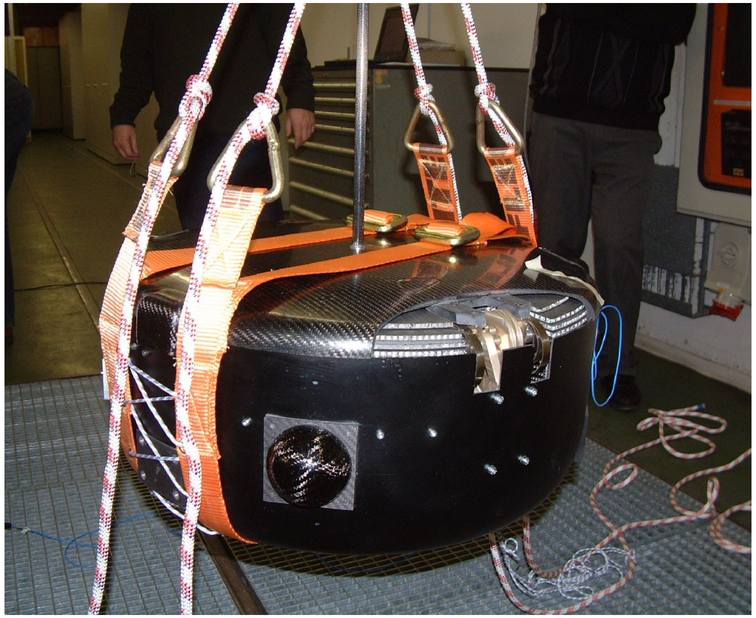


Steins and Lutetia flybys

Future events

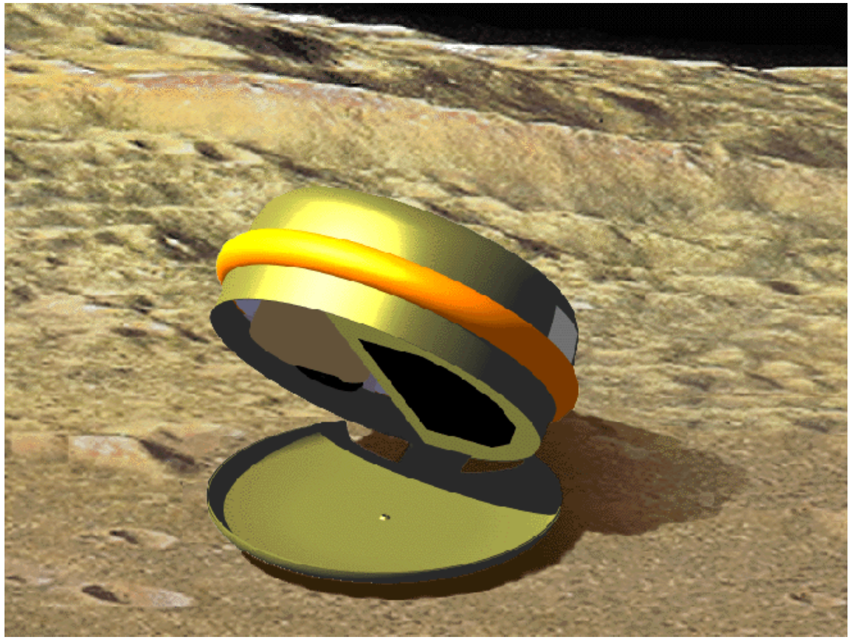


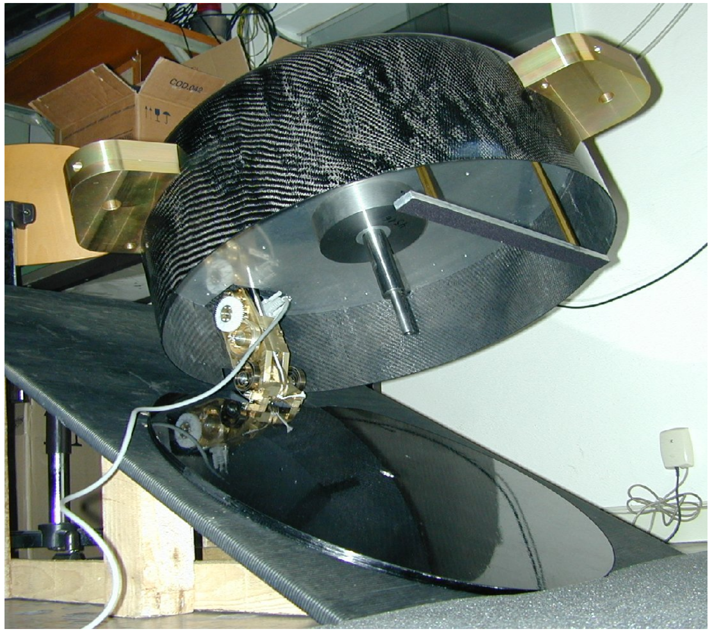
Landing Shock Tests on NetLander



- Drop tests in the airbag belts (180 g deceleration) and impact tests on sand and on hard ground were successfully performed
- NetLander survives 2.5 m/s on hard ground without any damage
- Internal payload and subsystem units can be shock-protected by mounting on the internal baseplate, which is only softly coupled with the „hard“ structure
- ⇒ No airbags are needed for landing scenarios with ≈ 1 m/s

Landing in Upside-Down Position





In case of upside-down landing, the opening mechanism of the lid will tilt the Lander until it falls (very slowly) into the upright position.

Repeated attempts are possible.

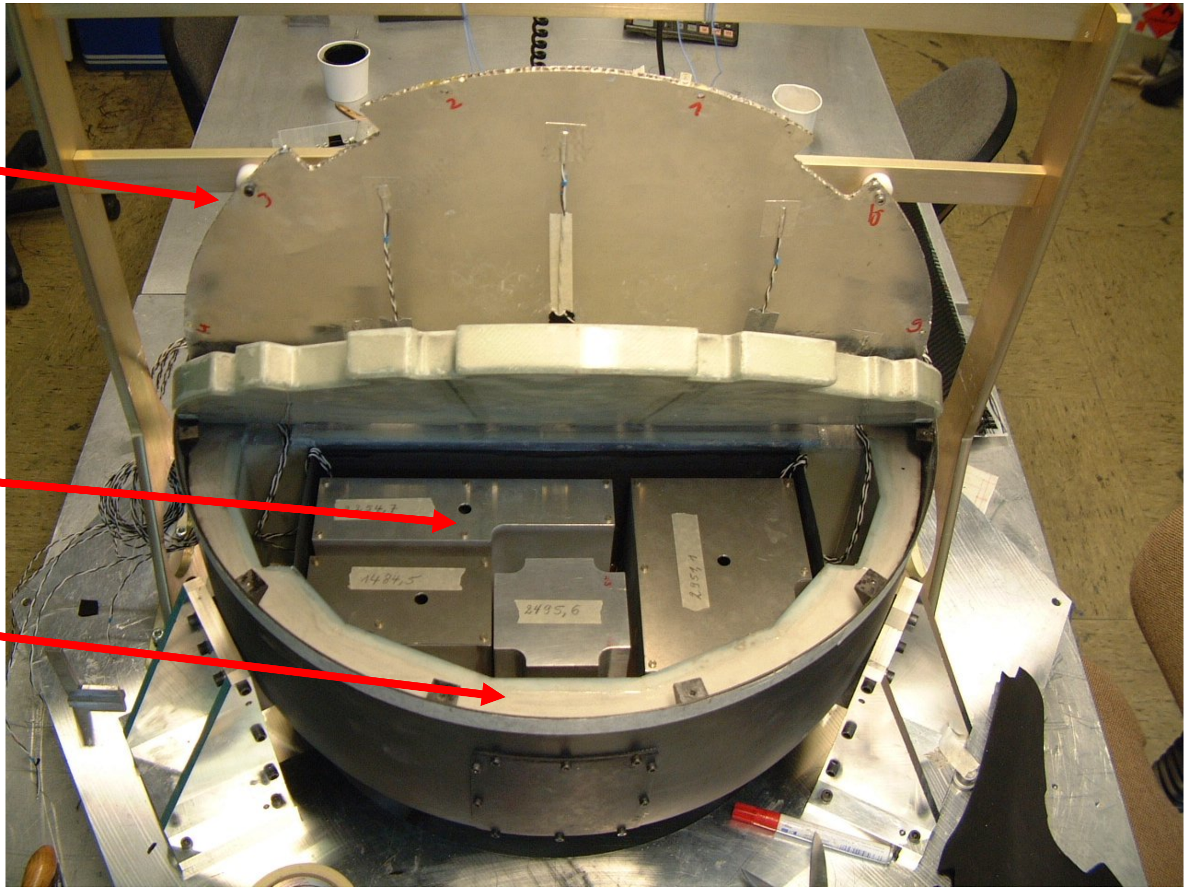
The uprighting mechanism was developed and qualified for Mars environment, and can be adapted to very-low-gravity environment.

Structural Configuration (without the Lid)

Payload instruments on this side

Mass dummies of E-boxes

Silica isolation



Primary structure (carbonfiber)	**2980 g**
Lid (not shown on the photo)	**1350 g**